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Demonstration of Three Corrosion-Resistant Sustainable Roofing Systems

Final Report on Project F08-AR02

David M. Bailey, L.D. Stephenson, Karl Palutke, Lawrence Clark, and Mike Merrick

June 2013

Construction Engineering Research Laboratory

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Final report

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Abstract

The purpose of this Corrosion Prevention and Control (CPC) demonstration was to investigate the life-cycle cost impact of three corrosion-resistant roofing technologies that provide several secondary benefits over the outdated roofing systems they replace. Fort Bragg, NC, was selected as the location to demonstrate (1) a heat-resistant metal shingle roofing system with above-sheathing ventilation (ASV), (2) a sloped-roof conversion using standing-seam metal roofing system with heat-shedding coating, and (3) a fiberglass-reinforced plastic (FRP) panel roofing system with ultraviolet (UV) radiation protection. Metrics were established to evaluate improvements in performance, corrosion resistance, and energy efficiency over older conventional roofing. Performance was documented through data collection, observation, and reports by facility users.

None of the demonstrated technologies was found to provide sufficient return on investment (ROI) to warrant their selection solely to improve building energy efficiency. The ASV and slope-conversion methods could be modified to reduce first costs to improve their applicability in properly selected cases. The FRP panel roofing provides a modest ROI and provides interior daylighting benefits in applications such as equipment maintenance sheds and workshops without climate control.

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Preface

This demonstration was performed for the Office of the Secretary of Defense (OSD) under Department of Defense (DoD) Corrosion Control and Prevention Project F08AR02, "Corrosion Resistant Sustainable Self-Cooling Roof and Fiberglass Roof". The proponent was the US Army Office of the Assistant Chief of Staff for Installation Management (ACSIM), and the stakeholder was the US Army Installation Management Command (IMCOM). The technical monitors were Daniel J. Dunmire (OUSD(AT&L)), Bernie Rodriguez (IMPW-FM), and Valerie D. Hines (DAIM-ODF).

The work was performed by the Materials and Structures Branch (CEERD-CF-M) of the Facilities Division (CF), US Army Engineer Research and Development Center – Construction Engineering Research Laboratory (ERDC-CERL). A portion of this work was performed by Mandaree Enterprise Corporation (MEC), Warner Robins, GA. Roofing design was performed by Penta Engineering Group, Inc. At the time this report was prepared, Vicki L. Van Blaricum was Chief, CEERD-CF-M; L. Michael Golish was Chief, CEERD-CF; and the Martin J. Savoie, CEERD-CV-T, was Technical Director for Installations. The Deputy Director of ERDC-CERL was Dr. Kirankumar Topudurti and the Director was Dr. Ilker Adiguzel.

The following Fort Bragg personnel are gratefully acknowledged for their support and assistance in this project:

- John Rose – Architect, Directorate of Public Works (DPW)
- Fred Plummer – Construction Representative, DPW.

The Commander of ERDC was COL Kevin J. Wilson and the Director was Dr. Jeffery P. Holland.

Executive Summary

Roof-related maintenance and repair (M&R) activities comprise a large part of Department of Defense (DoD) facility operation and maintenance (O&M) requirements. US Army O&M costs for roofing M&R exceeds $200 million dollars annually. The service life of roofing systems used on DoD facilities typically ranges from 20 – 30 years. Because the design life of permanent buildings is at least 40, the facility life cycle is always expected to include major roof repair and replacement. Postponing or avoiding roof replacement through the use of long-life roofing systems can reduce facility life-cycle costs. When major roof repair and replacement projects are needed, opportunities arise to apply newer technologies that will significantly improve upon the performance of the previous roof; durability, energy efficiency, drainage, and aesthetics can be cost-effectively addressed concurrently as part of a single project.

The purpose of this Corrosion Prevention and Control (CPC) demonstration was to investigate the life-cycle cost impact of three corrosion-resistant roofing technologies that provide several secondary benefits over the outdated systems they replace. Fort Bragg, NC, was selected as the location to demonstrate (1) a heat-resistant metal shingle roofing system with above-sheathing ventilation (ASV), (2) a sloped-roof conversion using standing-seam metal roofing system with heat-shedding coating, and (3) a fiberglass-reinforced plastic (FRP) panel roofing system with ultraviolet (UV) radiation protection. Metrics were established to evaluate improvements in performance, corrosion resistance, and energy efficiency over older conventional roofing. Performance was documented through data collection, observation, and reports by facility users.

The metal shingle with ASV was found to have a return on investment (ROI) of 0.28. The system was determined to have promise for properly selected applications where the properties of metal are desired and corrosion resistance is a key specification. It can enhance the appearance of standard metal roofs and potentially mitigate certain vulnerabilities of asphalt shingles to wind and hail damage. The documented energy savings in the Fort Bragg application were not sufficient to warrant widespread implementation in a similar climate. In cases where corrosion resistance is not an important performance characteristic, ASV could be applied in con-

junction with conventional insulation methods to enhance facility energy efficiency.

The SSMR slope-conversion demonstration provided an ROI of –0.07. It eliminated the ponding-related problems that caused the existing membrane roof to degrade and leak and provided a desired aesthetic upgrade. However, the purpose-engineered steel truss superstructure for supporting the deck added more cost than would be necessary in most applications of this technology, and the estimated energy-consumption benefits do not warrant use of the technology solely for energy conservation purposes. Application costs on similar buildings could be achieved using a more conventional lightweight framing structure to support the metal deck. Consideration of this solution should include a project-specific life-cycle cost/benefit study to determine viability.

The FRP panel roof replacement was determined to provide and ROI of 2.63. The demonstration showed that the use of this material to replace a failed metal roof can be beneficial for buildings that are not climate-controlled and where there is no ceiling to obstruct daylight transmission into the interior space. An FRP panel roof can provide significant benefits, including better indoor lighting, improved thermal comfort, and lower energy bills, when used on buildings such as craft shops, warehouses, and industrial facilities.

The overall project ROI for all three technology demonstrations was 1.08.

Unit Conversion Factors

Multiply	By	To Obtain
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
feet	0.3048	meters
gallons (US liquid)	3.785412 E-03	cubic meters
inches	0.0254	meters
mils	0.0254	millimeters
square feet	0.09290304	square meters

1 Introduction

1.1 Problem statement

Roofing is a major component comprising the Department of Defense (DoD) building stock that must be periodically replaced due to materials degradation (Kumar 2006). Roof-related maintenance and repair (M&R) activities comprise a large part of DoD facility operation and maintenance (O&M) requirements. US Army O&M costs for roofing M&R exceeds $200 million dollars annually.

The expected service life of the roofing systems commonly used by DoD, including low-slope membranes, asphalt shingles, and standing seam metal, is 20–30 years (Cash 1997, Schneider 1997). Because permanent buildings have a design life of 40 years or more, major roof repair and replacement are part of the life cycle. Issues affecting roof replacement include high replacement costs, high disposal costs (including environmental compliance), and disruption of mission-related activities. Postponing or avoiding roof replacement through the use of long-life roofing systems could help to reduce roof life-cycle costs.

Each roofing type has its inherent set of problems. Metal roofing is subject to coating deterioration and corrosion, particularly in humid and coastal climates. Low-slope roofing is susceptible to ponding from poor drainage, which can accelerate membrane degradation and lead to serious leakage. Conventional shingles are subject to aging of the asphalt and loss of granules. All roofs are susceptible to damage caused by weather events such as high winds and hail.

Because the Military Construction (MILCON) program now focuses on major building renovation instead of new construction, replacement and upgrade of building components will be a frequent requirement for facility managers. Major repair and replacement projects bring opportunities to replace outdated roofs with new technologies that will significantly improve upon the performance of the original roofing systems. Improvement of energy efficiency, drainage, and other attributes such as aesthetics and comfort can be cost-effectively addressed as part of these replacement projects. This project demonstrates three corrosion-resistant systems with the potential to significantly improve performance and reduce life-cycle costs.

1.2 Objective

The objective of this project was to demonstrate three innovative roof technologies on existing Army facilities: (1) heat-resistant metal shingle roofing system with above-sheathing ventilation (ASV), (2) sloped roof conversion using a standing-seam metal roofing system with heat-shedding coating, and (3) a fiberglass-reinforced plastic panel roofing system with ultraviolet radiation protection.

1.3 Approach

The demonstrated technologies were evaluated for improvements in performance, corrosion resistance, and energy efficiency over conventional roofing systems now in place in Army facilities. Commercially available examples of the subject technologies were assessed for use in the project. The project team worked with the Fort Bragg Directorate of Public Works (DPW) to select candidate buildings for each technology.

Performance assessment of these roofing products included testing coupons made from each of the three roofing materials. Some were placed on an exposure rack at Fort Bragg. Others were sent to a laboratory for accelerated corrosion testing. The roofing materials were monitored for performance for 1 year. Additionally, humidity/temperature sensors were placed in the buildings with the stone-coated metal shingle roofs to evaluate impact on temperature and humidity in the attic space.

Mandaree Enterprises Corporation (MEC) was selected as the general contractor for the project, and a Professional Engineer from Penta Engineering Group, Inc., developed a design for each roof. The designs were reviewed by subject matter experts from the Engineer Research and Development Center – Construction Engineering Research Laboratory (ERDC-CERL) and US Army Engineer District – Louisville. Performance metrics related to corrosion resistance and energy efficiency were established to help quantify demonstration results.

A preliminary meeting was held with representation from ERDC-CERL, the Fort Bragg DPW, and the contractors. Health and safety plans, work plans and quality control plans were provided and approved by the government before work began.

2 Technical Investigation

2.1 Project overview

Fort Bragg, SC, is located in a region where the climate is favorable to the corrosion of steel structures and building components. In the summer, the average high temperature is 90 °F, and the average low in the winter is 31 °F. It averages 47 in. of rain annually. The region records a high number of cooling-degree days, which provides a good opportunity to evaluate building comfort and energy-related benefits potentially offered by the selected technologies during the cooling season.

Three roofing technologies were installed as reroofing projects. A corrosion-resistant, stone-coated metal shingle roof with an enhanced ventilation system was installed over existing asphalt shingles on two small office buildings. A multistory building with low-slope membrane roof was retrofitted using a steep-slope metal panel roofing system with a high-performance coating. The severely corroded metal panel roofs on three small utility warehouses were removed and replaced with a fiberglass panel roofing system.

The roofing systems were installed independently of one another by different contractors during the spring and summer of 2008.

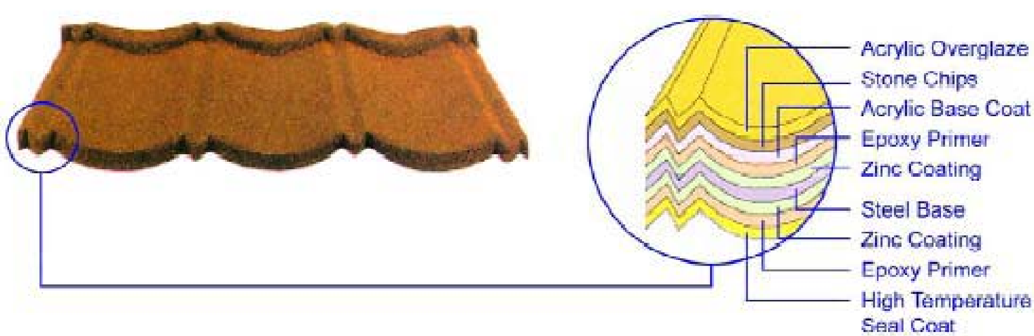
2.2 Technology description

The selected technologies are expected to mitigate corrosion and materials degradation as compared with conventional roofing systems. They can also provide benefits such as energy efficiency and building comfort. The stone-coated metal shingle system and metal panel roof with high-peformance coating have material properties that help to reduce surface temperatures. The demonstrated applications of both systems incorporate added ventilation below the new roof substrates to improve energy efficiency during the cooling season. The fiberglass-reinforced plastic panel system takes advantage of its light transmission qualities to provide daylighting inside the building, reducing electric demand for indoor lighting.

2.2.1 Stone-coated metal shingle system with ASV

The stone coated metal shingle used in this demonstration is manufactured by Decra Roofing Systems, Inc.* They derive their corrosion resistance from multiple coating layers, which include a zinc coating over a steel substrate, epoxy primer over the zinc coating, and a layer of stone chips encased in a corrosion- and UV-resistant acrylic binder (Figure 1). The stone chips provide additional protection from heat and abrasion. The "fawn grey" color that was chosen is ENERGY STAR® qualified (http://www.energystar.gov) and has an initial solar reflectance of 0.25 and unchanged reflectance of 0.25 after 3 years of exposure. The shingles have a very good initial thermal emissivity value of 0.97. This product, when installed on a pitch of 4 in. over 12 in. or more, qualifies for a 50-year warranty from the manufacturer with protection against damage from hail and wind up to 120 mph.

Figure 1. Material layers in stone-coated metal shingle. Source: www.decra.com.



The project design consisted of a roof recover and incorporation of an ASV system. For this demonstration, the existing asphalt shingle roof and its supporting deck function as a bottom sheathing for the added ventilated space. To create the necessary air space, a plywood substrate is fastened to rows of battens running parallel to the roof slope. The battens serve as spacers between the new substrate and existing roof and create channels that allow air to flow along the underside of the new substrate. Air can enter and exit through vent openings at the soffit and ridge. The intent of ASV is to reduce the temperature of the existing above-attic sheathing during the cooling season, potentially reducing the attic temperature and improving building energy efficiency (Beal 1995). ASV also can provide

* Decra Roofing Systems, Inc., 1230 Railroad Street, Corona, CA 92882. http://www.decra.com/

improved resistance to condensation in the attic during the heating season.

The metal shingle roofing systems were installed at Building 3-2631 Figure 2 and Building 8-3846 Figure 3. Building 8-3846 is located next to a structurally identical building (3-3249), which was used as a control to monitor the effects of the demonstrated technology on attic conditions. Temperature and relative humidity sensors were installed in all three buildings to assess performance.

Figure 2. Building 3-2631 with original roof.

Figure 3. Building 8-3846 with original roof.

2.2.2 Slope conversion using metal roofing system with high-performance coating

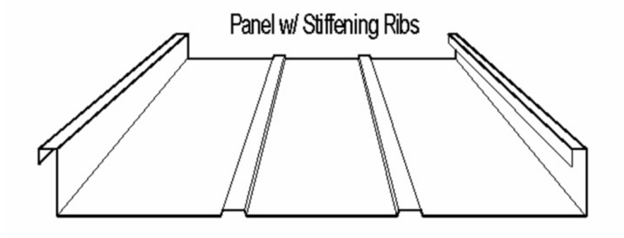
A structural standing-seam metal roof (SSMR) with a 5:12 slope was installed on Building H-5834 (Figure 4), covering an in-place low-slope membrane roof with parapet walls. The roof was constructed of a mechanically attached black ethylene propylene diene monomer (EPDM) membrane over insulation board attached to metal decking.

Figure 4. Building H-5834 with original low-slope roof and parapets.

The Construction Metal Products CMP S-2500 18 in. panel SSMR system was selected for the demonstration.* The 26-gauge galvalume-coated steel panel has an additional protective coating comprised of a high performance resin (70% polyvinylidiene fluoride (PVDF)) and a "cool pigment" (PPG Industries, Inc. DURANAR ULTRA-Cool). The coating provides optimal corrosion resistance. The color, sierra tan, was chosen to match the surrounding building architecture. It has an initial solar reflectance of 0.49, a solar reflectance of 0.45 after 3 years of exposure, and an emissivity value of 0.83. The dark rubber EPDM membrane already in place had a solar reflectance of 0.06 and thermal emissivity of 0.06. The panel profile and description can be found in Figure 5.

* Construction Metal Products, Inc., 2204 West Front Street, Statesville, NC 28677. http://www.cmpmetalsystems.com/

Figure 5. Replacement panel profile.
Source: Construction Metal Products, Inc.



The SSMR system manufacturer states that it is appropriate for roof slopes as low as ½:12. However, adding a sloped SSMR roof over top of the existing low-slope roof eliminates water intrusion into the roofing system and building interior caused by clogged drains, which had occurred in the past on this building (Figure 6). Conversion to a steep-slope roofing system also provided the opportunity to incorporate a ventilated attic space above the original roof deck. An engineering analysis determined that the existing roof could accommodate the new structure above it.

Figure 6. Ponding on pre-demonstration roof due to clogged drains.

2.2.3 Fiberglass-reinforced plastic (FRP) panel system

FRP panel roofing was popular in the early 1960s as residential patio roof covers. The pre-engineered building industry also used light-transmitting skylight panels made from this material to promote energy efficiency, as it reduced the need for artificial lighting inside structures such as commercial warehouses. However, the products typically used in those applica-

tions were not intended to serve as load-bearing structural components because of their to susceptibility to degradation from prolonged UV exposure. As the chemical composition of the plastic binders improved, the performance of the FRP roof materials proved practical for such exposure. Panels that are now available have been engineered to bear loads and can be used over entire roof areas.

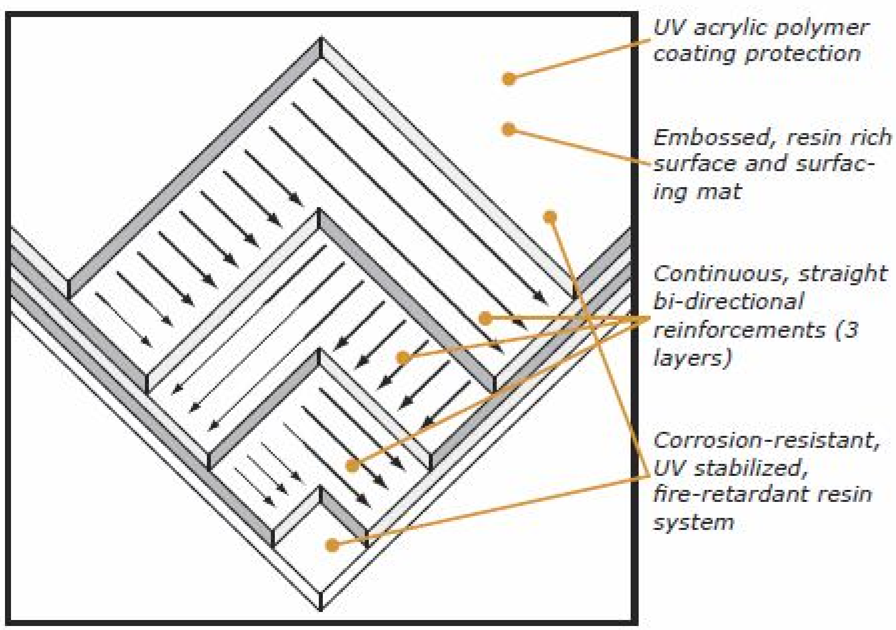
One such product, Tuff Span® from Enduro Composites*, was selected to demonstrate as a replacement for severely corroding metal roofs on three pre-engineered metal buildings (Buildings 3-1735, 3-1736, and 3-1737). All three buildings, similar in size and construction, are used for storage of grounds maintenance equipment (Figure 7). The FRP replacement panel has a corrugated profile (Figure 8) and is composed of a lightweight multi-layer material that is corrosion and chemical resistant (Figure 9). The product is expected to provide improved corrosion resistance and better protection against water intrusion that can cause damage to the material and equipment stored in the buildings.

Figure 7. Pre-demonstration metal roof on one of the project buildings.

* Enduro Composites, Inc., 16602 Central Green Blvd., Houston, TX 77032. http://www.endurocomposites.com/products/building-products/fiberglass-roof-deck/overview.

Figure 8. Installed FRP panel showing corrugated profile.

Figure 9. Example of layering FRP panels with coating systems including internal UV resistant coatings. Source: Enduro product literature, www.enduro.com.



The three buildings had no interior ceilings or climate control. A white translucent color was selected for its high light transmission properties—up to 50% of outdoor ambient light. The new panel was expected to improve interior daylighting in comparison to the skylight panels then in place.

It was originally intended that a fiberglass roofing system with a layer of polytetrafluoroethylene (PTFE), for UV resistance, be used in this phase of the demonstration. However, PTFE-coated fiberglass roofing was not available commercially when the demonstration roofs were designed.

2.3 Roof installation

2.3.1 Stone-coated metal shingle system with ASV

Stone-coated metal shingle roofs were installed on Buildings 8-3846 and 3-2631 at Fort Bragg, NC, during July 2009. The existing asphalt shingle roofs on both buildings, which were left in place, did not have any major damage or leaks. The installation process for both roofs was mostly the same, with the only significant difference being that Building 8-3486 had a hip roof instead of a gable configuration.

For both roof installations, the first step was to attach battens over the existing asphalt shingles. The battens consisted of nominal 2 x 4 boards spaced 2 ft apart and fastened to the truss chords that support the in-place roof deck. Attachment and layout of the battens for Building 3-2631 can be seen in Figure 10. Once the battens were in place, 0.5 in. thick exterior plywood sheathing was added and secured to the battens with fasteners to create the base for the new roofing system (Figure 10). Figure 11 shows the air gaps created above the previous roof by the battens and sheathing. Design loads and fastening requirements for the battens and sheathing are detailed in the project design drawings (Appendix A).

Figure 10. Attachment of plywood sheathing, Building 3-2631.

Figure 11. Air gap between existing and new roof, Building 8-3846.

The new sheathing was covered with one shingled layer of asphalt-saturated organic felt underlayment (ASTM D 228, Type 1). The stone-coated shingles were installed in accordance with the procedures recommended in the manufacturer's literature. The first rows of shingles, at the eave, were attached to an integrated starter clip/drip edge. The bottom edges of subsequent rows were locked into place with clips that are formed into the top edges of the preceding rows. This procedure is illustrated in a photo from the manufacturer's literature (Figure 12). As directed in the manufacturer's installation guidelines, the right side of each panel was compressed in order to interface with the side-lap locking mechanism formed into the left side of the adjoining panel at its right. Once each panel was locked into place, it was attached to the sheathing along the upper edge with four corrosion-resistant #8 hex-head screws.

Figure 12. Manufacturer's illustration of panel positioned to mate with the clip lock on panels in the course below.

The original attic space and the air gap between the new substrate and previous roof of both buildings are vented at the soffits and through the new ridge and hip vents. A rigid-roll corrugated plastic product was specified to provide vented closure at these locations. Details for the ridge and eave are shown in Figure 13 and Figure 14.

Figure 13. Vented ridge detail for Buildings 8-3846 and 3-2631.

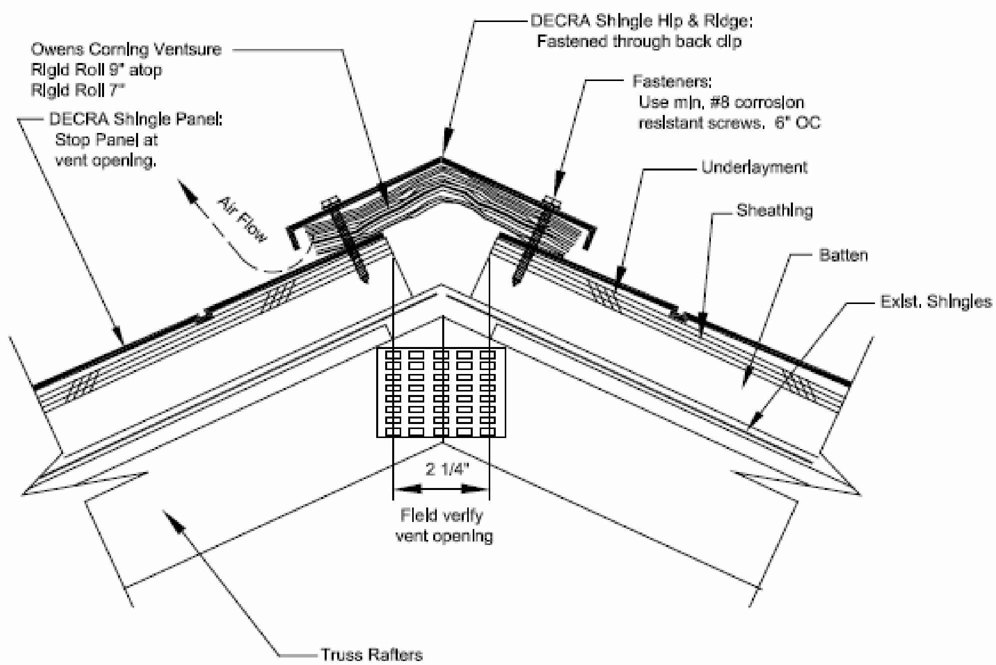
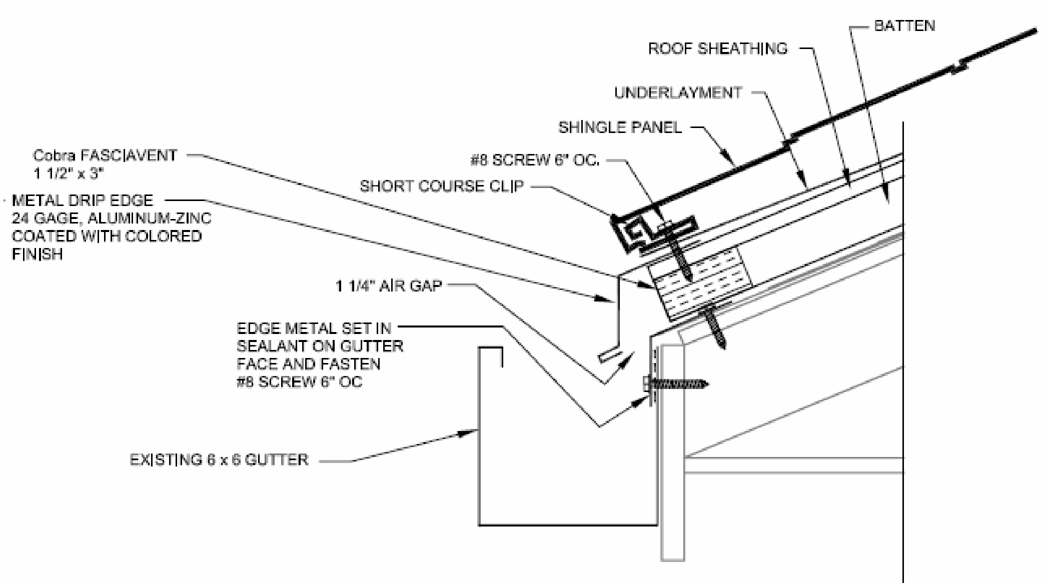


Figure 14. Vented eave detail for Buildings 8-3846 and 3-2631.



Specially fabricated stone-coated shingle components were installed to cap the ridge and hip lines at the intersections of two adjacent roof planes. A mocked-up view of the new ridge vent configuration (without battens or sheathing) is shown in Figure 15.

Figure 15. Ridge vent mockup for Building 3-2631.

With the new roofs installed on the buildings, all gutters were replaced to their original configuration. During the system installation on Building 3-2631, the general contractor noticed the existing gutters were not being raised in conjunction with the new roof, resulting in a drop of more than 2 in. from the new roof to the gutters (Figure 16).

Figure 16. Completed roofing system gutter detail, Building 3-2631.

The subcontractor's roofing engineer analyzed the configuration. Using the design rainfall conditions, analysis indicated that the gutter location was acceptable and able to contain runoff. These calculations are shown in Appendix B. The completed roofing system for Building 8-3846 is shown in Figure 17.

Figure 17. Completed roofing system Building 8-3846.

2.3.2 Slope conversion using SSMR system

The Building H-5834 conversion to a steep-sloped gable roof required the construction of a retrofit steel truss system. It consisted of six light-gage steel rafter frames (Figure 18), each of which was anchored to the building frame at four locations. Rafter frames were attached at their ends, along the perimeter of the roof, and at intermediate points aligned with the structural beams that support the original roof framing. Engineering drawings for the framing system and SSMR are provided in Appendix C.

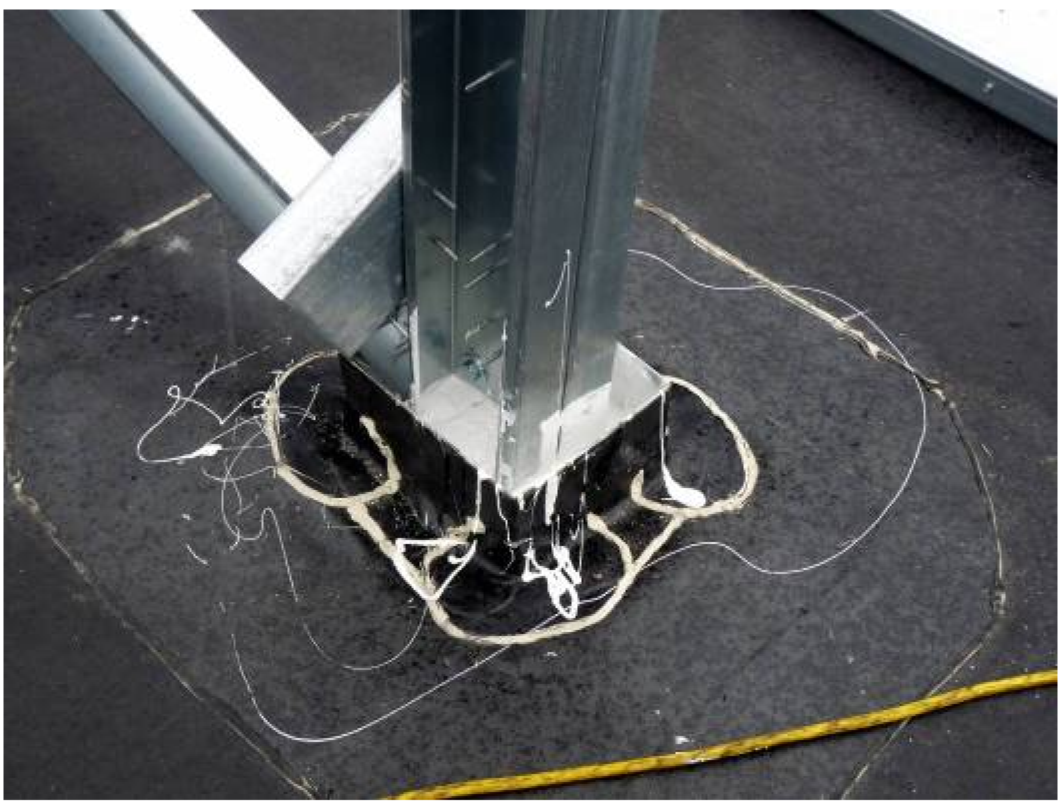
Figure 18. Rafter frame system for slope conversion retrofit.

A concrete pad was poured in-place at the frame-attachment points, one at each corner of the building. Each pad included vertical steel rods (3/8 in. diameter) embedded in the concrete and tied to the pad's reinforcement steel. These rods were used to secure a steel bracket to the surface of the pad. The pad was covered with new EPDM roofing membrane and seamed to the existing membrane to keep the building watertight during the construction period. Completed construction of the pad and bracket attachment can be seen in Figure 19. At the other 22 frame-attachment points, steel brackets were affixed directly to the existing roof beams by removing pieces of the roof decking to expose the needed locations (Figure 20). Penetrations through the EPDM membrane were sealed with pitch pans (Figure 21) to keep the roof watertight during construction.

Figure 19. Completed construction of pad and anchor bracket at corner.

Figure 20. Attachment of anchor bracket to roof beam at perimeter wall.

Figure 21. Pitch pan being constructed around roof penetration at attachment point.



Once in place, the new rafter frames were attached to the steel brackets. The purlins, which provide support and securement of the metal roofing

system, were then attached to the frames. The complete rafter frame system, with most of the purlins installed, can be seen in Figure 22.

Figure 22. Completed rafter system with some of the purlins installed.

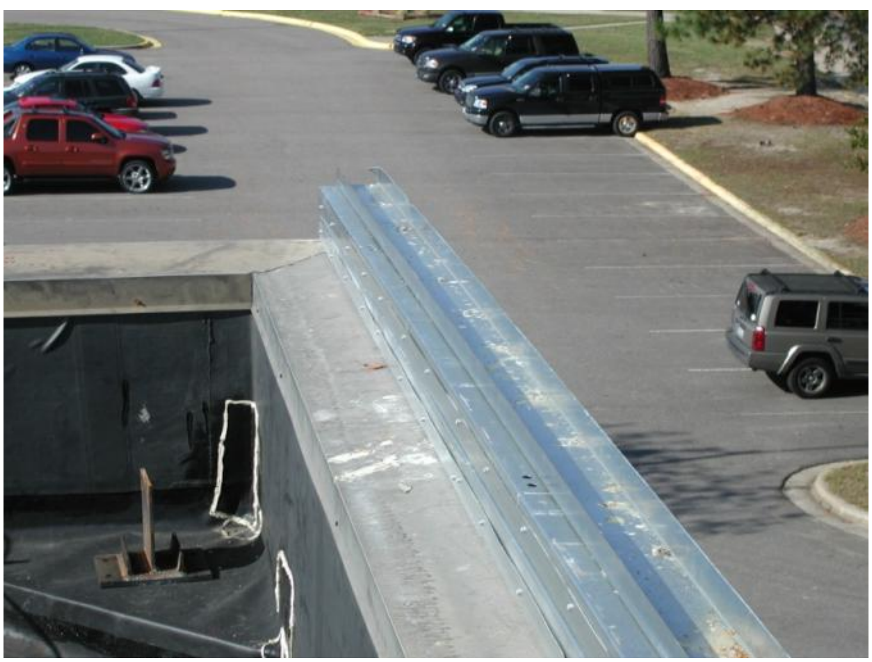
The SSMR was constructed with a fixed connection at the eave and sliding clip connections at the purlins and ridge to allow for thermal expansion and contraction of the roof panels. Because the panels are allowed to move along the slope of the roof, the roof framing required structural diaphragm bracing to be placed within the plane of the roof. This was done before the metal roof panels were installed. The completed roofing system is shown in Figure 23 and Figure 24.

Figure 23. Completed SSMR with existing powered bathroom exhaust relocated on top of the new roof.

Figure 24. Completed SSMR, exterior view.

To complete the building enclosure, exterior wall panels were constructed at both gable ends. This was accomplished by attaching steel blocking along the top of the parapet walls. For ease of construction, the blocking was fixed in place before the rafter frames were erected (Figure 25).

Figure 25. Steel blocking attached on parapet wall at gable end.



After completion of the SSMR, the metal wall frame was constructed (Figure 26), and a substrate of 0.5 in. thick fiberglass mat gypsum boards was attached to the studs (Figure 27). Next, an exterior insulation and fin-

ish system (EIFS) was installed to complete the construction. Venting of the new attic space between the old roof and the new SSMR roof (Figure 28) was provided by venting at the soffit (Figure 29) and ridge.

Figure 26. Steel stud wall frame at gable end, interior view.

Figure 27. Exterior wall at gable end before EIFS application.

Figure 28. Interior view of new attic space.

Figure 29. Ventilated soffit panel, attic interior view.

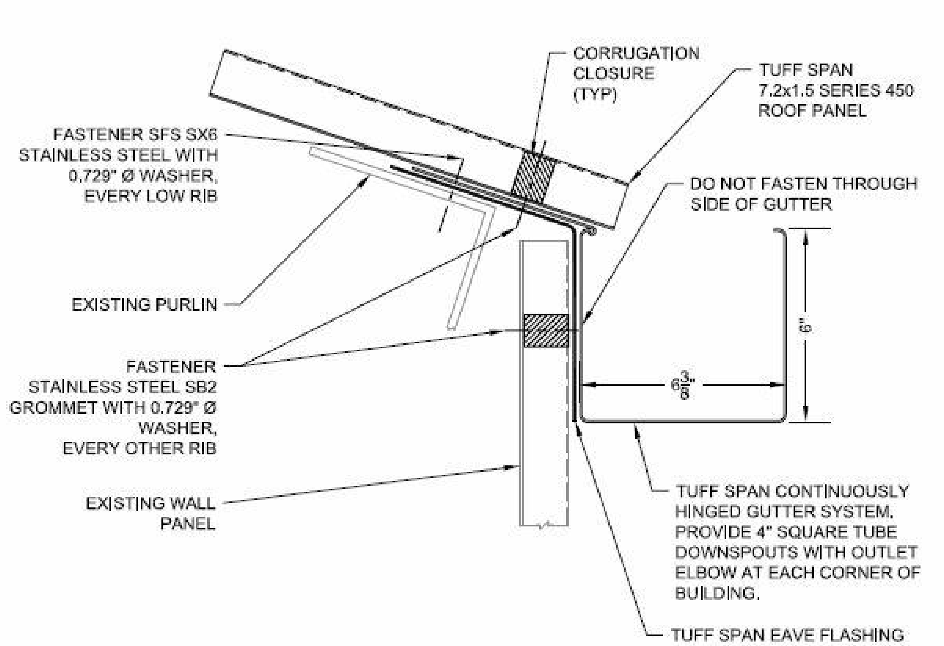
2.3.3 FRP panel system

The FRP roofing panel system was installed on each of the three pre-engineered buildings in a section-by-section progression to keep the building interiors covered at all times after work hours. The first step was to dismantle the existing downspouts and gutters. Next, the contractor's crew removed the metal roofing panels and integrated skylight panels using screw guns to extract the attachment screws (Figure 30). The support structure and roof purlins were left in place.

Figure 30. Removal of metal roof panels.

Once all of the metal roofing material was removed from a section, the crew installed the new FRP eave flashing piece by attaching it to the wall panel using grommet-type metal fasteners with neoprene sleeves. Next, the crew installed the gutter piece over the eave flashing. The roof panels were then placed over the upper flange of the gutter piece. The panels and gutter piece were then attached to a roof purlin using grommet-type self drilling metal fasteners placed through each lower rib of the panel. The drawing detail for the eave/gutter construction is shown in Figure 31.

Figure 31. Eave/gutter detail.



Using the same type of fasteners, the panel was attached directly to underlying purlins at each lower rib. The side laps of adjacent panels were joined with fasteners spaced at 18 in. through the high ribs. The layout of panel fasteners can be seen in Figure 32. After all panels were in place, an FRP cap piece was installed at the roof ridge and attached to underlapping panels (detail shown in Figure 33). The attachment was made using the fasteners having the neoprene sleeves placed at every-other high rib.

Figure 32. View showing layout of panel fasteners.

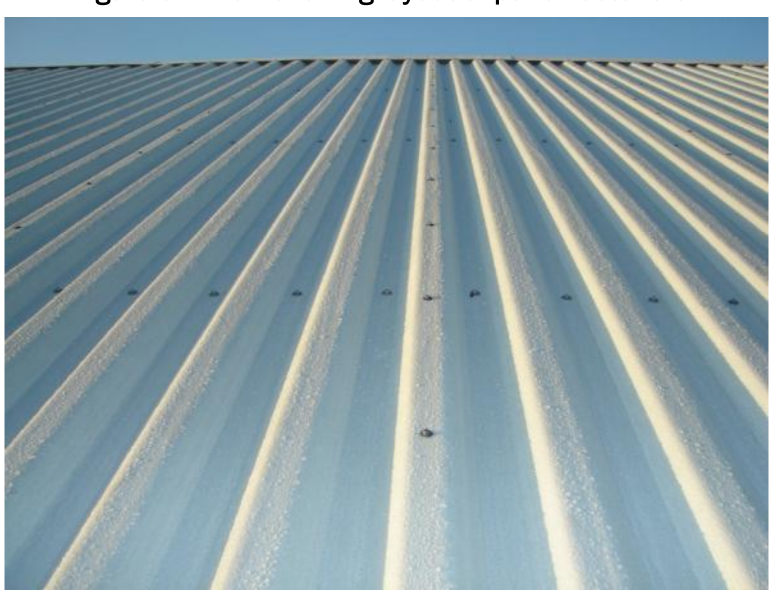
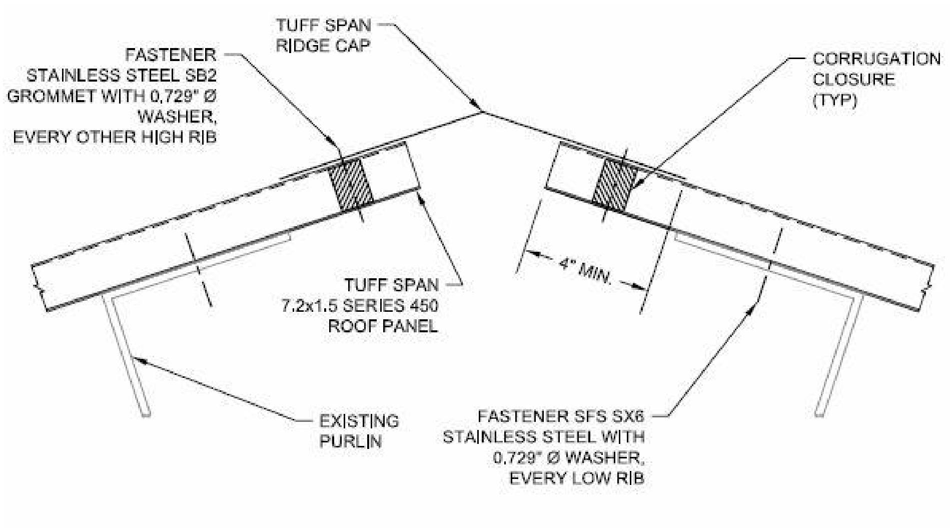


Figure 33. Ridge cap detail.



All fasteners, being made of stainless steel, have superior corrosion resistance. The grommet feature inhibits leakage at the fastener. Other system features that promote watertightness included a nonshrinking, nonhardening butyl tape field-applied in the lap area of all adjoining panels (Figure 34) and the placement of preformed foam panel closures at the openings under the panels located at the eaves.

Design drawings for the roofs are provided in Appendix D. The completed roofing system on one of the buildings is shown in Figure 35.

Figure 34. Application of butyl tap in lap seam.

Figure 35.View of completed FRP panel roof system.

2.4 Technology operation and monitoring

During the first year in place, the demonstration roofs were inspected periodically to look for signs of corrosion, defects, and leaks. Material samples from each of the three systems were exposed to outdoor weathering to assess corrosion resistance. Temperature and, in some cases, humidity readings were taken at various positions in the demonstration buildings.

2.4.1 Corrosion-resistance testing

Material specimens were cut from the delivered stock of each roof covering product. For the stone-coated metal shingle and the SSMR roof panels, 30 3 x 9 in. coupons were made. Half of them were scribed down to bare substrate using a rotary tool with a cutting wheel. For both materials, 12 scribed and 12 unscribed coupons were mounted on an exposure rack, along with 12 unscribed FRP panel coupons. This set of coupons was subjected to the Fort Bragg environment. Three scribed and three unscribed coupons of the two metal materials were sent to a materials testing laboratory to undergo accelerated aging tests. Results are discussed in Chapter 3.

2.4.2 Performance monitoring

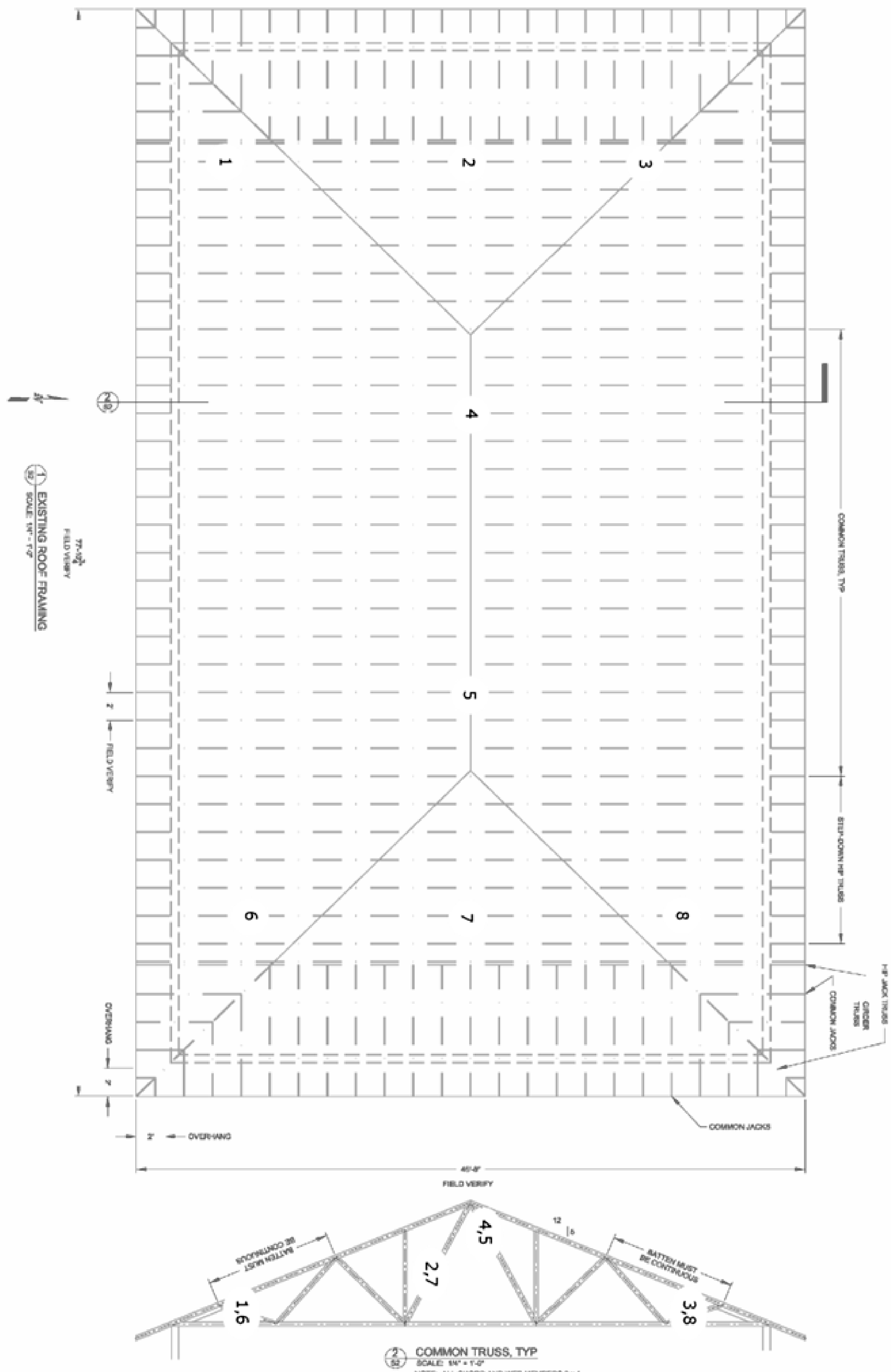
Sensors were installed in the ventilated attics spaces of the buildings with the stone-coated metal shingle system. The sensors capture temperature and relative humidity data at regular intervals. A similar system was

placed in the attic of the control structure, Building 8-3749, to provide baseline data for comparison and evaluation of shingle system performance. The control building and Building 8-3846 are adjacent to each other, and identical in age, size, and exterior design and construction. The OmniSense 900-S-1 sensors (Figure 36) were monitored wirelessly at 915 MHz by G-900-E wireless gateway that reports to the monitoring server through a cellular uplink. Both components were produced by OmniSense LLC*. The system provided a basis for evaluating the impact of the metal shingle system on building conditions as compared with the control facility. Sensor locations for these two buildings are shown in Figure 37.

Figure 36. OmniSense 900-S-1 sensor.

* OmniSense LLC, 72 Sams Point Road, Ladys Island, SC 29907. http://omnisense.com/.

Figure 37. Sensor locations, Buildings 8-3846 and 3-3749.



To monitor performance of the building with the SSMR slope-conversion retrofit, the contractor periodically visited the demonstration building to record temperatures beneath the SSMR roof and on the top floor of the building for comparison with outside ambient temperatures.

For the FRP panel demonstration buildings, temperatures inside the three buildings were recorded and compared with temperatures inside similarly constructed buildings in the near vicinity.

3 Discussion

3.1 Metrics

The weathering and corrosion metrics applied for measuring the success of the metal shingle and SSMR retrofit technologies were

- ASTM D 5894, *Standard Practice for Cyclic Salt Fog/UV Exposure of Painted Metal*
- ASTM G85, *Standard Practice for Modified Salt Spray (Fog) Testing,* Annex A5
- ASTM D 610, *Standard Test Method for Degree of Rusting on Painted Steel Surfaces*
- ASTM D 714, *Standard Test Method for Evaluating Degree of Blistering of Paints*
- ASTM D 1654, *Standard Test Method for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments.*

Coupons from the FRP roofing panels that were placed on the exposure racks were periodically inspected for fading, blistering, and delamination.

The demonstrated technologies also were evaluated to assess potential energy impacts related to each specific building application. Temperature and relative humidity were the metrics for attic spaces and/or building interiors as appropriate.

3.2 Results

3.2.1 Corrosion resistance and material performance

Half of both the scribed and unscribed coupons mounted on outdoor test racks were tested after 6 months of exposure, and the other half were tested after 11 months. For the accelerated weathering evaluation, half of the coupons were tested after 1,000 hours and the remaining half were tested after 2,016 hours.

The accelerated weathering protocol was ASTM D 5894. Material specimens were exposed to alternating periods of 1 week in a fluorescent UV/condensation chamber and 1 week in a cyclic salt fog/dry chamber. The fluorescent UV/ condensation cycle is 4 hours UV, 0.89 W at 340 nm

and 60 °C, using UVA-340 lamps, and 4 hour condensation at 50 °C. The fog/dry chamber runs a cycle of 1 hour dry-off at 35 °C. The fog electrolyte is 0.05% sodium chloride and 0.035% ammonium sulfate per ASTM G85, Annex A5.

A materials testing laboratory provided evaluation of the exposed coupons using ASTM D 610, ASTM D 714, and ASTM D 1654 as noted above.

After 1 year of weather exposure at Fort Bragg, the scribed coupons are beginning to show corrosion where the coating has been cut through to bare metal. These areas include at the scribe locations and the perimeter of the coupons. However, at the time of evaluation, corrosion was not spreading to areas beneath the coating layers. This can be seen in Figure 38. The unscribed shingles did not show any evidence of corrosion other than the cut edge at the specimen perimeter. After 1,000 hours of exposure, the scribed accelerated aging specimens all had corrosion present in the scribed area. In addition, one of the unscribed specimens showed the beginnings of corrosion around the perimeter, and the scribed coupons showed significant corrosion in the scribed areas. The corrosion had not produced blistering or cracking in the coating, however.

Figure 38. Corrosion in scribed metal shingle coupon.

There was no evidence of significant corrosion on any on the SSMR coupons that were placed on the exposure racks, scribed or unscribed.

None of the exposed FRP panel coupons has exhibited evidence of blistering, delamination, peeling, chalking, or any other environmental-related degradation.

3.2.2 Attic environment and roof temperature assessments

3.2.2.1 Stone-coated metal shingle system with ASV

To assess the representative thermal effects of this system, data for a typical summer day and winter day were analyzed.

A plot of the temperature data recorded on 16 July 2009 in the attics of Buildings 8-3846 and 3-3749 (the control building) at the northeast eaves is shown in Figure 39. The Fort Bragg ambient air temperatures for that day, taken from historical records, are also included. Fort Bragg had an afternoon rain shower between 1:55 p.m. and 3:55 p.m., which accounts for the abrupt temperature drop in the afternoon. Note that the attic temperature of the building with the metal-shingle roof system rose at a slower rate during the day and dropped at a slower rate during the night when compared to the attic of the control building. In comparison, the change in the demonstration building's attic temperatures during part of the day in which the rainstorm occurred, as well as in the evening, was steadier and fluctuated less. This result supports the idea that the combination of the metal shingles and the air gap created by the addition of the second layer of roofing may provide a thermal buffer over the original roofing system.

For that same date, a plot of the recorded relative humidity data versus time for the ambient air and the same sensors (northeast eave) in the two buildings is shown in Figure 40. Note that a period of 100% relative humidity of the outside air occurred during the rain followed by conditions of elevated relative humidity for the remainder of the day. During the time that the attic temperature of the control building was lower than that of the demonstration building, the attic's relative humidity readings were comparatively higher. This is consistent with expectations; with a constant amount of water vapor in the air, relative humidity decreases as temperature increases. In this case, although both attic spaces were ventilated, the rate of air exchange in the attic is slow enough to see this trend.

Figure 39. Temperature comparison between Buildings 8-3846 and 3-3749, northeast eaves (16 July 2009).

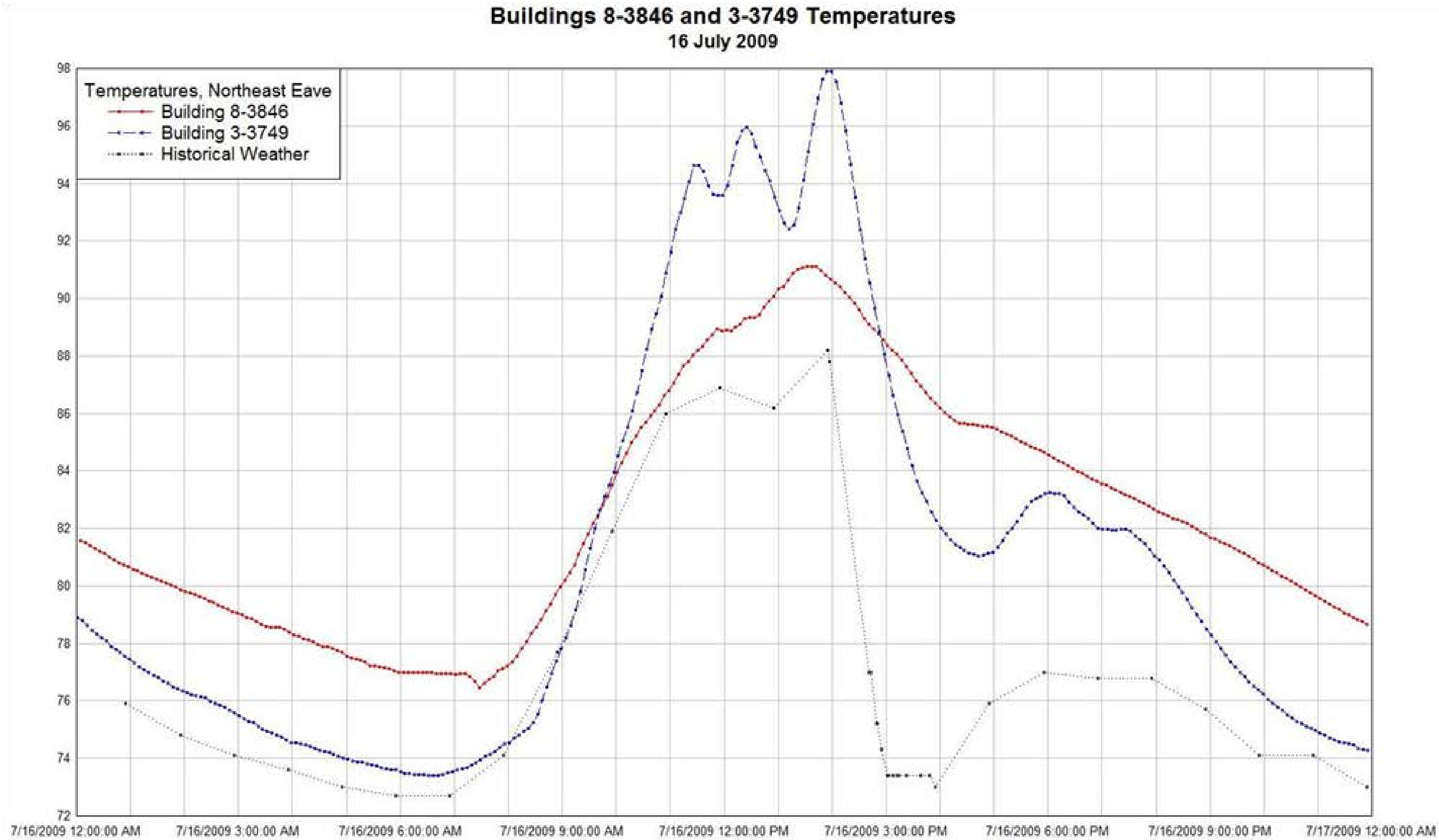
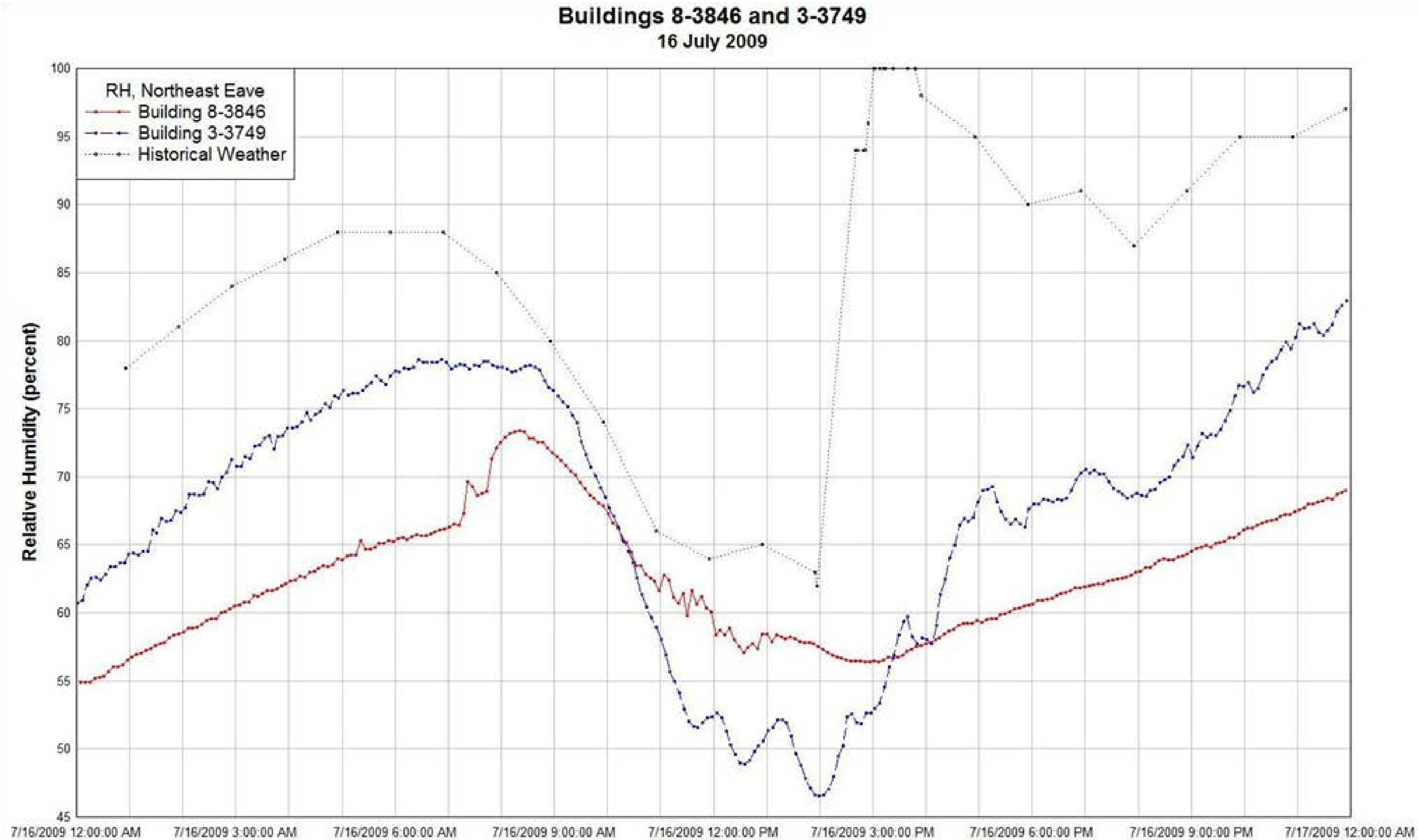


Figure 40. Relative humidity comparison between Buildings 8-3846 and 3-3749, northeast eaves (16 July 2009).



A plot of the recorded temperature data taken on that same day (16 July 2009) from a different set of attic sensors located at the northern peaks of Buildings 8-3846 and 3-3749 (the same buildings) is shown in Figure 41. As seen at the northeast eaves, the plots show the attic space of the metal-shingle roof with ASV changing in temperature at a slower rate than that of the control building. Also, the peak attic temperature during the day for the demonstration building is about 10 °F lower than was reached in the control building. These results indicate a potential for reducing cooling energy requirements during peak demand times.

In addition to examining the attic conditions during a summer day, the temperatures on a winter day (16 January 2010) were also examined. Figure 42 shows a plot of the attic temperatures at the northeast eaves on the two buildings on 16 January 2010. In this case, the demonstration building with the metal shingles and ASV held a higher attic temperature during the night. But as the daytime ambient air warmed up, the attic temperature fell below that of the control building. If the attic space is able to serve as a thermal buffer during the nighttime, it is possible that heating costs may be reduced during the winter. The same inference would indicate that heating costs could increase during the daytime. As seen for the summer comparison, the attic temperatures for the building with the stone-coated metal shingle and ASV change at a slower rate as compared to the attic of the control building.

Summary plots of the sensor data from the demonstration building and control building are available in Appendix E.

Figure 41. Temperature comparison between Buildings 8-3846 and 3-3749, attic peaks (16 July 2009).

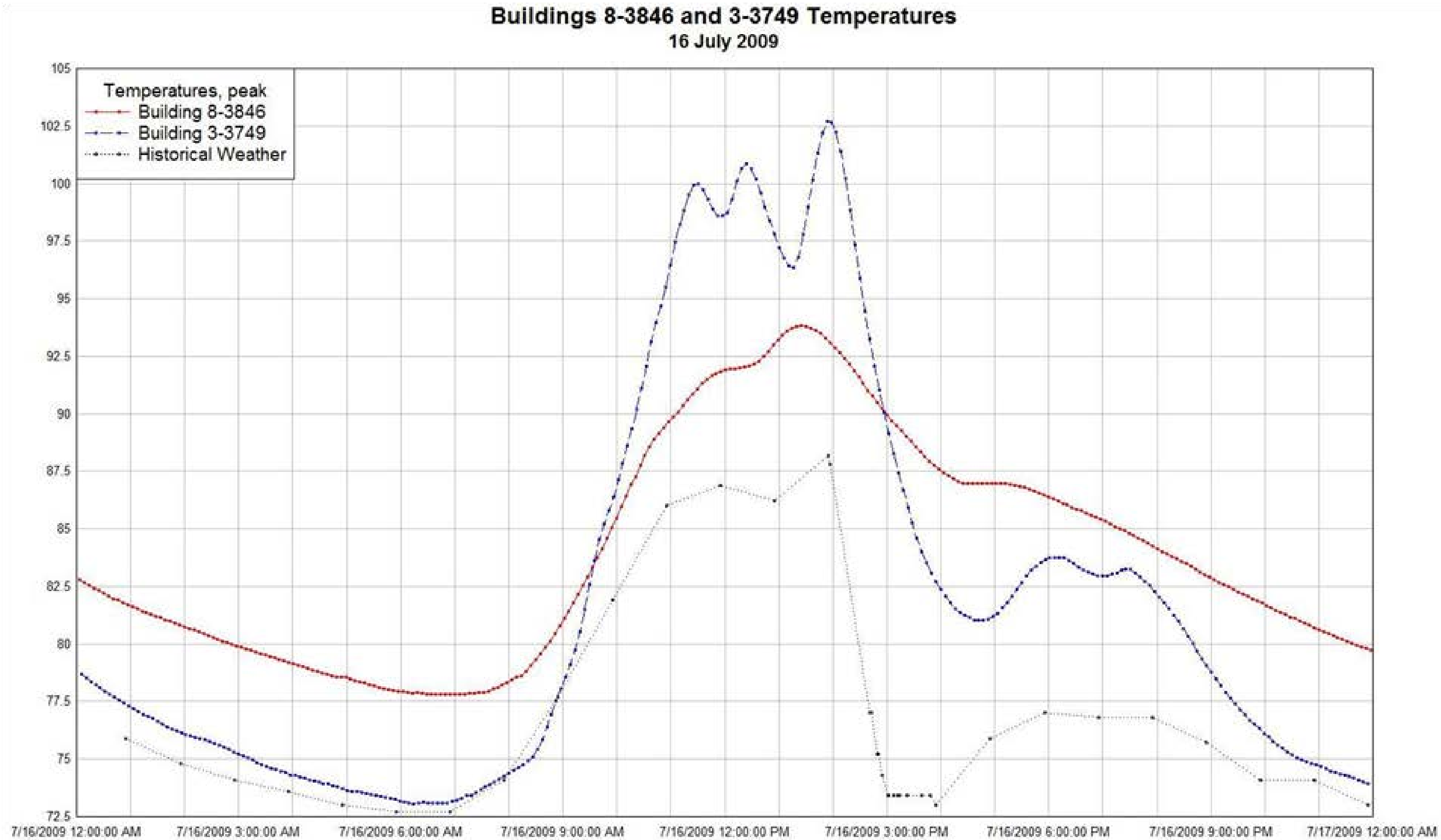
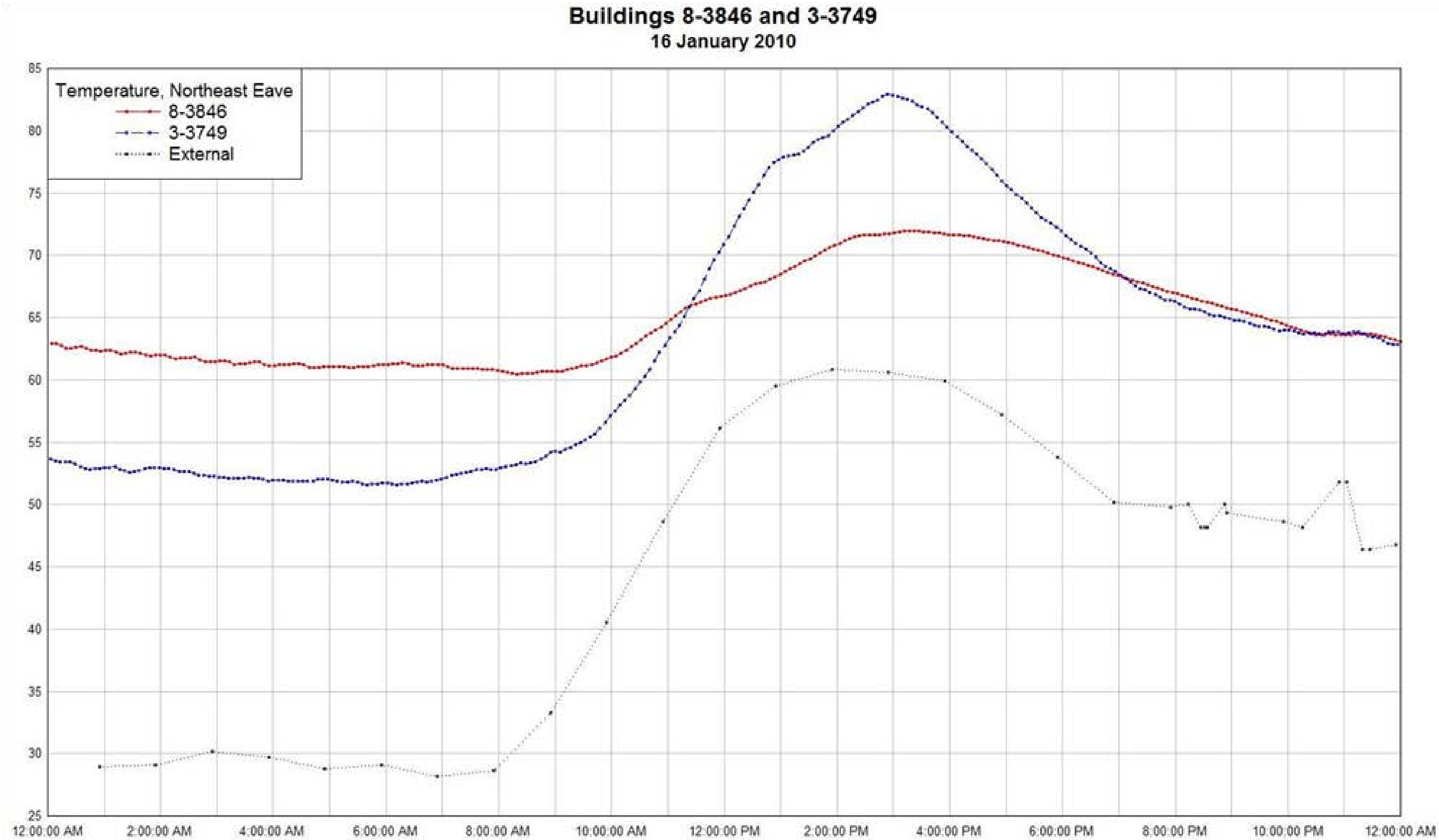


Figure 42. Temperature comparison between Buildings 8-3846 and 3-3749, northeast eaves (16 January 2010).



3.2.2.2 Slope conversion with SSMR system

During the afternoon of 13 April 2010, surface temperature readings were taken from the metal roofing panels and the original EPDM roofing membrane inside the new attic space of Building H-5834. For the EPDM surface, readings were taken at three locations on the southwest side of the roof, with the average being 90 °F. The exterior SSMR surface was inaccessible due to its height, so measurements were taken on the underside of the panels. The average panel surface temperature approximately 160 °F. During the same time, the ambient outdoor temperature was 83.3 °F.

On 8 September 2010 at 10:50 a.m., another set of readings was taken. The three surface measurements of the EPDM membrane were 104.9 °F, 106.0 °F, and 105.3 °F. The temperature readings taken on the underside of the metal panels were 125.3 °F, 124.6 °F, and 127.5 °F. Top-floor interior temperature of the building was 72 °F, and the ambient outdoor temperature was 87 °F. The weather was sunny with prevailing wind speed of 18 mph.

Others have documented roof component temperatures and heat flux for various roof systems (Gillenwater 2005). Studies have shown that EPDM roof membrane can reach surface temperatures approaching 180 °F on a hot, sunny day. For Building H-5834, the temperature of the EPDM membrane inside the attic was considerably lower than these values. The data indicate that the demonstrated steep-slope SSMR has created a thermal buffer between itself and the in-place EPDM surface. During the cooling season, these lower surface temperatures can reduce the heat flux through the original insulation and thereby improve building energy efficiency.

3.2.2.3 FRP panel system

For each of the unconditioned demonstration buildings, temperature measurements were taken on three different days from the surface of the panel at two adjacent locations on the southeastern part of the roof. On 13 April 2010, with an ambient air temperature of 85 °F, the roof panel temperatures of Buildings 3-1735, 3-1736, and 3-1737 were measured to be 112 °F, 112 °F, and 111 °F, respectively. In comparison, the roof surface temperature of a similar metal-roofed building in the area (Building 3-2436) was 132 °F. On 17 May 2010, averages for the two roof-panel surface temperatures on the three buildings were 81 °F, 91 °F, and 88 °F.

On 8 September 2010, the roof panel temperatures for Buildings 3-1735, 3-1736, and 3-1737 were 85 °F, 83 °F, and 82 °F, respectively. At the time that the panel measurements were taken, the outdoor ambient air temperature was 81 °F and the interior temperatures were 82 °F.

During the visits, grounds maintenance workers expressed satisfaction with the light-transmitting characteristics of the FRP panel roofing, stating that there was rarely a need to use electric lighting inside the buildings during daylight hours. The additional diffuse interior lighting provided by the translucent FRP panels proved to be much greater than the project team had expected (see Figure 43).

Figure 43. View of building interior showing affect of additional ambient lighting provided by FRP roof.

3.3 Lessons learned

When designing and building a roofing system with ASV, it is important to make sure the roofing system in place is functioning as designed. It was necessary to remove shingles that were covering the ridge vent on Building 3-2631 before installation of the new system. Also, gutter height needs to be evaluated to make the gutters will continue to capture runoff adequately when the roof profile is raised to accommodate ASV. For Building 3-2631, the effectiveness of the gutter system was not impacted significantly by leaving it at its original height after the new deck was installed.

The slope conversion using an SSMR system proceeded without unforeseen problems since the components and materials are all well understood by qualified roofing designers and practitioners.

The translucent FRP roofing panel system transmitted more light to the building interiors than expected by the project team. Technicians who work on equipment inside the demonstration storage buildings attested to improvement of interior working conditions resulting from increased levels of diffuse ambient interior lighting.

4 Economic Summary

The projected return of investment (ROI) for each of the three demonstrated technologies was developed based on the actual project costs. In addition to implementation costs, expenditures accounted for here include performance monitoring and CPC project management costs. Application of these technologies by an installation would not require those additional expenditures.

4.1 Costs and assumptions

The project-wide expenses for mobilization and warranties are equally divided among the three demonstration tasks. Baseline costs (in 2008) for conventional repair and replacement were obtained principally from RS Means Publications (Mossman 2008, Waier 2008).

4.1.1 Stone-coated metal shingle system with ASV

The installation costs for the metal-shingle system with ASV for the two project buildings are shown in Table 1. The total project cost for the demonstration was $232K. With a 50 year manufacturer's warranty, the service life of this system is expected to be significantly greater than the asphalt shingle systems that had been previously installed.

Table 1. Installation cost for stone-coated metal shingle system with ASV.

Item	Cost
Labor	$31,240
Materials	$41,580
Other direct costs	$8,283
Profit	$9,528
Total	$90,631

A major assumption in this analysis is that the new roofing and ASV systems will affect conductive heat transfer between the attic and the occupied spaces in a manner that will provide energy savings for the buildings. To quantify heat loss, conductive heat transfer values were calculated for Building 8-3846 using Fourier's equations and assuming a constant attic

temperature. These calculations were performed for three time periods: (1) 15 July 2009 through 30 September 2009; (2) 1 April 2010 through 15 July 2010 (assuming an interior temperature of 78 °F during cooling season) and (3) 1 October 2009 through 31 March 2010 (assuming an interior temperature of 68 °F during heating season). The attic temperatures were taken to be the average of the readings from the sensors mounted in the lower region of the attic. The attic temperatures that would be expected if the new technology had not been implemented were assumed to be the same as the attic temperatures of the control building. For all calculations, an R-value of 19 was used for the attic insulation and a coefficient of performance (COP) of 1.5 was used for the building air conditioners.

The computed results indicate an energy savings of 2.56 million BTU for air conditioning, and 1.32 million BTU for heating for Building 8-3846. Using an electrical power rate of $0.08 per kWh and natural gas rate of $1.07 per therm provides a total cost savings of $1,089 per year (US Department of Energy 2013). Extrapolating those savings for Building 3-2361 results in an annual energy savings of $2,430 for both buildings combined.

The baseline scenario for performing the ROI analysis assumes that the existing asphalt shingle roofs on both buildings were removed and replaced with similar asphalt shingle systems at a cost of $2.81 per square foot (SF). The cost of $3,344 for gutters and downspouts was also included. The roofs were assumed to need a tear off and replacement after 20 years of service life. Annual maintenance costs for the stone coated metal shingle system and conventional inorganic asphalt shingle are assumed to be $0.02/SF and $0.05/SF, respectively.

4.1.2 Slope conversion using SSMR system with high-performance coating

Construction cost for the sloped-roof conversion using the SSMR system with high-performance coating on Building H-5834 was $136K (Table 2). The total project cost for the demonstration was $349K. The new system is expected to provide a longer service life (in excess of 30 years) than the low-slope EPDM membrane previously covering the roof.

Table 2. Installation costs for slope roof conversion using SSMR system with high-performance coating.

Item	Cost
Labor	$56,656
Materials	$40,858
Other direct costs	$24,305
Profit	$14,373
Total	$136,192

The computed energy savings are based solely on the reflectivity and emissivity properties of the metal roof panel as determined using the Department of Energy heating and cooling calculator for sloped roofs (US Department of Energy 2013). For the Fort Bragg region, the results indicate a savings of $53 a year. The analysis is based on an insulation R value of 5 and COP of 1.5, with energy costs of $0.082/kWh and $1.07/therm for natural gas. It is possible that the enclosed attic space created by the new sloped roof could provide additional energy savings in a similar manner as the ASV with the metal-shingle system, there is not enough data to quantify that supposition.

The baseline scenario assumes that the failed EPDM membrane roof was removed and replaced with another EPDM membrane system and additional tapered insulation. Costs for the replacement were computed to be $9.02/SF and the service life is assumed to be 20 years. After 20 years the failed EPDM roof would be removed and replaced with a similar system. An annual maintenance cost of $0.06/SF is used for the EPDM roof.

The demonstration utilized a steep slope (5 in./ft) for the SSMR, which required an engineered steel truss frame. Many roof slope conversions that have been implemented on similar buildings such as military barracks use a lower slope of 3 in./ft or less. Reducing the slope, allows for use of a lightweight metal framing system with rafters and knee walls (Rosenfield 1984) in lieu of trusses, which can significantly cut both material and labor costs. The benefits of eliminating ponded water, reducing annual maintenance costs, extending roof service life, providing a ventilated attic space, and employing cool-roof technology can still be realized by using this less-steep design. Therefore, for assessing the potential savings of the SSMR slope conversion, it is assumed that the typical project would use the lower slope and lightweight framing alternative.

For this ROI analyses, it is also assumed that each year, 10 projects of similar scope will be undertaken Army-wide; each replacing a failed membrane roofing system on a similar building with the demonstrated technology. A conservative project cost reduction of 60% of the demonstration installation cost, related to eliminating the need for the engineered truss system, is also used. Applying these cost savings, and eliminating the travel and per diem costs incurred in the demonstration project, the unit cost for the proposed slope conversion projects is approximately $12.60/SF. The annual maintenance cost for the SSMR roofs with high-performance coatings is assumed to be $0.01/SF.

4.1.3 FRP panel system

The project costs apportioned to the demonstration totaled $379K. The total construction cost of the FRP panel roofing system for all three buildings (2,520 SF per building) was $148K, with a breakdown shown in Table 3. Extracting travel, per diem, and other administrative-type costs incurred in the demonstration project, the resulting equivalent unit cost for installing the FRP panel roofing system with new gutters and downspouts was $8.08/SF. An expected service life of 30 years was used for the new FRP panel roofs, and the annual maintenance cost is $0.01/SF.

Table 3. Installation costs for FRP panel system.

Item	Cost
Labor	$55,584
Materials	$60,721
Other Direct Costs	$16,312
Profit	$15,649
Total	$148,266

This analysis assumes that the FRP system will save costs related to reduced interior lighting requirements resulting from daylighting through the translucent roofing material. Each building has nine fluorescent light fixtures with two 40-watt tubes each. Without the FRP panel roof, it is assumed that the lights are turned on during 75% of working hours throughout the year. Accounting for typical amounts of overcast, cloudy, and rainy weather, it is estimated that with the FRP panel roofs the lights will be turned on about 25% of the time. Assuming an electricity cost of $0.082 per kWh, the annual energy savings would be $59 per building.

Fort Bragg personnel have remarked that the buildings' interior temperatures are more comfortable than previously, when the metal roofs were in place, and that the new interior daylighting effect has improved working conditions. To estimate the potential benefit of increased productivity, a quarter man-hour per day is assumed for each building with an FRP panel roofing system. For a fully burdened labor rate of $35/hour and a 200-day year, the annual savings is $1,750.

The baseline scenario assumes that 30 Army installations located in warmer regions of the United States have equipment storage buildings of similar design and construction without climate control. During each of the next 15 years, the roofs on these buildings at two of the installations will reach the end of their service lives. Unit costs to remove the failed roofs and replace them with standard 24 gauge galvanized steel corrugated roofs are $1.8/SF and $2.57/SF, respectively. The cost for new gutters and downspouts is $607 per building. Maintenance and repair of metal roofs costs $0.06/SF annually, and the expected service life is 15 years.

The yearly costs and benefits for the baseline and new technology scenarios are shown in Table 4.

Table 4. Yearly costs and benefits for baseline and new technology scenarios.

	Baseline				New Technology			Benefits		
Yr	buildings re-roofed	Remove & replace with metal	Annual maintenance	Total	Remove & replace with FRP panel	Annual maintenance	Total	Energy savings	Productivity Savings	Total
1	3	$33,037	$454	$33,491	$379,000	$76	$379,076	$177	$5,250	$5,427
2	6	$66,074	$1,361	$67,435	$122,170	$227	$122,396	$531	$15,750	$16,281
3	6	$66,074	$2,268	$68,342	$122,170	$378	$122,548	$885	$26,250	$27,135
4	6	$66,074	$3,175	$69,250	$122,170	$529	$122,699	$1,239	$36,750	$37,989
5	6	$66,074	$4,082	$70,157	$122,170	$680	$122,850	$1,593	$47,250	$48,843
6	6	$66,074	$4,990	$71,064	$122,170	$832	$123,001	$1,947	$57,750	$59,697
7	6	$66,074	$5,897	$71,971	$122,170	$983	$123,152	$2,301	$68,250	$70,551
8	6	$66,074	$6,804	$72,878	$122,170	$1,134	$123,304	$2,655	$78,750	$81,405
9	6	$66,074	$7,711	$73,786	$122,170	$1,285	$123,455	$3,009	$89,250	$92,259
10	6	$66,074	$8,618	$74,693	$122,170	$1,436	$123,606	$3,363	$99,750	$103,113
11	6	$66,074	$9,526	$75,600	$122,170	$1,588	$123,757	$3,717	$110,250	$113,967
12	6	$66,074	$10,433	$76,507	$122,170	$1,739	$123,908	$4,071	$120,750	$124,821
13	6	$66,074	$11,340	$77,414	$122,170	$1,890	$124,060	$4,425	$131,250	$135,675
14	6	$66,074	$12,247	$78,322	$122,170	$2,041	$124,211	$4,779	$141,750	$146,529
15	6	$66,074	$13,154	$79,229	$122,170	$2,192	$124,362	$5,133	$152,250	$157,383
16	0	$33,037	$13,154	$46,192	$0	$2,192	$2,192	$5,133	$152,250	$157,383
17	0	$66,074	$13,154	$79,229	$0	$2,192	$2,192	$5,133	$152,250	$157,383
18	0	$66,074	$13,154	$79,229	$0	$2,192	$2,192	$5,133	$152,250	$157,383
19	0	$66,074	$13,154	$79,229	$0	$2,192	$2,192	$5,133	$152,250	$157,383
20	0	$66,074	$13,154	$79,229	$0	$2,192	$2,192	$5,133	$152,250	$157,383
21	0	$66,074	$13,154	$79,229	$0	$2,192	$2,192	$5,133	$152,250	$157,383
22	0	$66,074	$13,154	$79,229	$0	$2,192	$2,192	$5,133	$152,250	$157,383
23	0	$66,074	$13,154	$79,229	$0	$2,192	$2,192	$5,133	$152,250	$157,383
24	0	$66,074	$13,154	$79,229	$0	$2,192	$2,192	$5,133	$152,250	$157,383
25	0	$66,074	$13,154	$79,229	$0	$2,192	$2,192	$5,133	$152,250	$157,383
26	0	$66,074	$13,154	$79,229	$0	$2,192	$2,192	$5,133	$152,250	$157,383
27	0	$66,074	$13,154	$79,229	$0	$2,192	$2,192	$5,133	$152,250	$157,383
28	0	$66,074	$13,154	$79,229	$0	$2,192	$2,192	$5,133	$152,250	$157,383
29	0	$66,074	$13,154	$79,229	$0	$2,192	$2,192	$5,133	$152,250	$157,383
30	0	$66,074	$13,154	$79,229	$0	$2,192	$2,192	$5,133	$152,250	$157,383

4.2 Projected return on investment (ROI)

4.2.1 Stone-coated metal shingle system with ASV

The total project costs for the demonstration was $232K. Overall, the calculated ROI for this technology is 0.28. Details of the calculation are shown in Table 5. The ROI is negatively skewed due to the required inclusion of CPC-specific project costs as part of the investment. However, for this particular implementation on the buildings at Fort Bragg, the additional service life and energy savings provided by the stone coated metal shingles does not offset the high material costs when compared to commodity asphalt shingles

Table 5. ROI analysis for stone-coated metal shingle system with ASV on two project buildings.

Investment Required			232,000
Return on Investment Ratio	0.28	Percent	28%
Net Present Value of Costs and Benefits/Savings	2,008	68,026	66,018

A Future Year	B Baseline Costs	C Baseline Benefits/Savings	D New System Costs	E New System Benefits/Savings	F Present Value of Costs	G Present Value of Savings	H Total Present Value
1	28,000		-	2,430		28,440	28,440
2	440		175	2,430	153	2,507	2,354
3	440		175	2,430	143	2,343	2,200
4	440		175	2,430	134	2,190	2,056
5	440		175	2,430	125	2,046	1,922
6	440		175	2,430	117	1,912	1,796
7	440		175	2,430	109	1,787	1,678
8	440		175	2,430	102	1,670	1,568
9	440		175	2,430	95	1,561	1,466
10	440		175	2,430	89	1,459	1,370
11	440		175	2,430	83	1,364	1,280
12	440		175	2,430	78	1,274	1,197
13	440		175	2,430	73	1,191	1,118
14	440		175	2,430	68	1,113	1,045
15	440		175	2,430	63	1,040	977
16	440		175	2,430	59	972	913
17	440		175	2,430	55	909	853
18	440		175	2,430	52	849	797
19	440		175	2,430	48	794	745
20	440		175	2,430	45	742	696
21	28,000		175	2,430	42	7,349	7,307
22	440		175	2,430	39	648	608
23	440		175	2,430	37	605	568
24	440		175	2,430	34	566	531
25	440		175	2,430	32	529	496
26	440		175	2,430	30	494	464
27	440		175	2,430	28	462	434
28	440		175	2,430	26	432	405
29	440		175	2,430	25	404	379
30	440		175	2,430	23	377	354

4.2.2 Slope conversion using SSMR system with high-performance coating

The total project costs for the demonstration of this technology was $349K. Based on the costs and assumption presented in section 4.1.2, the 30-year ROI is –0.07 (Table 6). It should be noted that the ROI was determined based on using a more economical lightweight metal framing system, not the engineered steel truss framing system that was demonstrated in the project. For the baseline and demonstration scenarios used in the analysis, if costs for the slope conversion are reduced by less than 2% or additional energy savings can be shown, a positive ROI can be achieved.

Table 6. ROI analysis for slope roof conversion with SSMR and high-performance coating.

Investment Required			349,000
Return on Investment Ratio	-0.07	Percent	-7%
Net Present Value of Costs and Benefits/Savings	4,488,043	4,464,176	-23,867

A Future Year	B Baseline Costs	C Baseline Benefits/Savings	D New System Costs	E New System Benefits/Savings	F Present Value of Costs	G Present Value of Savings	H Total Present Value
1	288,640		327,987	2,130	306,537	271,754	-34,783
2	288,640		364,430	4,260	318,293	255,819	-62,474
3	288,640		364,430	6,390	297,484	240,833	-56,651
4	288,640		364,430	8,520	278,024	226,703	-51,320
5	288,640		364,430	10,650	259,839	213,394	-46,445
6	288,640		364,430	12,780	242,820	200,836	-41,984
7	288,640		364,430	14,910	226,931	189,021	-37,910
8	288,640		364,430	17,040	212,098	177,906	-34,193
9	288,640		364,430	19,170	198,213	167,418	-30,796
10	288,640		364,430	21,300	185,240	157,543	-27,697
11	288,640		364,430	23,430	173,141	148,264	-24,876
12	288,640		364,430	25,560	161,807	139,505	-22,302
13	288,640		364,430	27,690	151,238	131,277	-19,962
14	288,640		364,430	29,820	141,326	123,499	-17,827
15	288,640		364,430	31,950	132,069	116,182	-15,888
16	288,640		364,430	34,080	123,432	109,305	-14,127
17	288,640		364,430	36,210	115,379	102,848	-12,531
18	288,640		364,430	38,340	107,835	96,753	-11,081
19	288,640		364,430	40,470	100,765	90,999	-9,766
20	577,280		364,430	42,600	94,169	160,177	66,008
21	577,280		364,430	44,730	88,010	150,215	62,206
22	577,280		364,430	46,860	82,252	140,868	58,617
23	577,280		364,430	48,990	76,858	132,080	55,222
24	577,280		364,430	51,120	71,829	123,858	52,028
25	577,280		364,430	53,250	67,128	116,144	49,016
26	577,280		364,430	55,380	62,755	108,944	46,189
27	577,280		364,430	57,510	58,637	102,138	43,501
28	577,280		364,430	59,640	54,810	95,793	40,982
29	577,280		364,430	61,770	51,239	89,850	38,612
30	577,280		364,430	63,900	47,886	84,251	36,365

These results support the view that slope conversion for failed low-slope membrane roofing systems can be a viable option if a lightweight framing system is used. However, these projects must be considered and evaluated on a case-by-case basis. A life-cycle cost analysis for a particular project should include local roof construction and maintenance costs, energy costs, and expected roof service life (Sharp 1988).

4.2.3 FRP panel system

The total project costs for the demonstration of this technology were $379K, resulting in a 30-year ROI of 2.63. Details of the analysis can be seen in Table 7.

Table 7. ROI analysis for FRP panel system.

Investment Required			379,000
Return on Investment Ratio	2.63	Percent	263%
Net Present Value of Costs and Benefits/Savings	998,504	1,995,287	996,782

A Future Year	B Baseline Costs	C Baseline Benefits/Savings	D New System Costs	E New System Benefits/Savings	F Present Value of Costs	G Present Value of Savings	H Total Present Value
1	33,037			5,805		36,302	36,302
2	66,074		122,170	17,415	106,703	72,920	-33,783
3	66,074		122,170	29,025	99,727	77,630	-22,097
4	66,074		122,170	40,635	93,203	81,409	-11,795
5	66,074		122,170	52,245	87,107	84,362	-2,745
6	66,074		122,170	63,855	81,402	86,572	5,170
7	66,074		122,170	75,465	76,075	88,137	12,062
8	66,074		122,170	87,075	71,103	89,133	18,030
9	66,074		122,170	98,685	66,448	89,613	23,165
10	66,074		122,170	110,295	62,099	89,649	27,550
11	66,074		122,170	121,905	58,043	89,309	31,266
12	66,074		122,170	133,515	54,243	88,618	34,374
13	66,074		122,170	145,125	50,700	87,648	36,947
14	66,074		122,170	156,735	47,377	86,405	39,028
15	66,074		122,170	168,345	44,274	84,954	40,679
16	33,037		-	168,345		68,208	68,208
17	66,074		-	168,345		74,217	74,217
18	66,074		-	168,345		69,365	69,365
19	66,074		-	168,345		64,817	64,817
20	66,074		-	168,345		60,574	60,574
21	66,074		-	168,345		56,612	56,612
22	66,074		-	168,345		52,908	52,908
23	66,074		-	168,345		49,439	49,439
24	66,074		-	168,345		46,204	46,204
25	66,074		-	168,345		43,180	43,180
26	66,074		-	168,345		40,367	40,367
27	66,074		-	168,345		37,718	37,718
28	66,074		-	168,345		35,257	35,257
29	66,074		-	168,345		32,959	32,959
30	66,074		-	168,345		30,803	30,803

The analysis supports the use of FRP panel systems to replace corroded metal roofing on non-climate-controlled buildings similar to those used in the demonstration. Candidate buildings are those that would benefit from no-cost daylighting provided by the translucent FRP panels. In highly corrosive environments, the FRP system may be even more competitive with low-cost metal roofing. Application to additional buildings at Army installations and other services installations would increase the ROI.

4.2.4 Overall project

Table 8 consolidates the three individual ROI analyses. The overall ROI for this CPC project was 1.08.

Table 8. Combined ROI for three demonstration projects.

Investment Required			960,000
Return on Investment Ratio	1.08	Percent	108%
Net Present Value of Costs and Benefits/Savings	5,488,555	6,527,489	1,038,933

A Future Year	B Baseline Costs	C Baseline Benefits/Savings	D New System Costs	E New System Benefits/Savings	F Present Value of Costs	G Present Value of Savings	H Total Present Value
1	349,677		327,987	10,365	306,537	336,495	29,959
2	355,154		486,775	24,105	425,149	331,245	-93,904
3	355,154		486,775	37,845	397,354	320,805	-76,549
4	355,154		486,775	51,585	371,360	310,301	-61,059
5	355,154		486,775	65,325	347,070	299,802	-47,268
6	355,154		486,775	79,065	324,338	289,320	-35,018
7	355,154		486,775	92,805	303,115	278,944	-24,170
8	355,154		486,775	106,545	283,303	268,709	-14,594
9	355,154		486,775	120,285	264,757	258,591	-6,165
10	355,154		486,775	134,025	247,428	248,650	1,222
11	355,154		486,775	147,765	231,267	238,937	7,670
12	355,154		486,775	161,505	216,128	229,397	13,269
13	355,154		486,775	175,245	202,011	220,116	18,104
14	355,154		486,775	188,985	188,771	211,017	22,246
15	355,154		486,775	202,725	176,407	202,175	25,768
16	322,117		364,605	204,855	123,492	178,485	54,994
17	355,154		364,605	206,985	115,434	177,973	62,539
18	355,154		364,605	209,115	107,887	166,967	59,081
19	355,154		364,605	211,245	100,813	156,609	55,796
20	643,794		364,605	213,375	94,214	221,493	127,279
21	671,354		364,605	215,505	88,052	214,177	126,124
22	643,794		364,605	217,635	82,291	194,425	112,133
23	643,794		364,605	219,765	76,895	182,125	105,229
24	643,794		364,605	221,895	71,864	170,627	98,764
25	643,794		364,605	224,025	67,160	159,852	92,692
26	643,794		364,605	226,155	62,785	149,805	87,020
27	643,794		364,605	228,285	58,665	140,318	81,653
28	643,794		364,605	230,415	54,837	131,481	76,645
29	643,794		364,605	232,545	51,263	123,213	71,950
30	643,794		364,605	234,675	47,909	115,431	67,522

5 Conclusions and Recommendations

5.1 Conclusions

5.1.1 Stone-coated metal shingle system with ASV

Corrosion-resistant metal shingle roofing may offer benefits where corrosion resistance is specified and potential subsidiary benefits such as hail or wind resistance are advisable to explore. The ability of the demonstrated shingles to reject heat combined with their UV resistance and multiple coating layers makes them both corrosion resistant and capable of reducing solar heat absorption. When used in conjunction with an ASV system, they can be designed to provide an insulating air space in a roofing system. However, the energy savings produced in this specific demonstration application are not sufficient to justify the additional cost of installing these high performance materials. In addition, some of the observed thermal benefit could be obtained by using a conventional asphalt shingle in conjunction with the ASV used in this project. Alternately, energy savings can be obtained by increasing the amount of attic insulation in the buildings.

5.1.2 Slope conversion using SSMR system with high-performance coating

This SSMR application can provide long-lasting roofs with lower maintenance requirements than conventional membrane roofing systems. A steep roof avoids ponding problems and can enhance architectural appearance. For these reasons, the use of these systems has been very popular when converting low-slope roofing systems on existing barracks buildings to steeper slopes. They have played a significant role in the Army Barracks Upgrade Program since the 1990s. However, unlike the demonstration project, which used an engineered truss framing system, these projects typically utilize a less-expensive lightweight framing system.

When using a lightweight frame, the added cost for roof-slope conversion can be offset by providing longer service life and reduced maintenance costs. Energy efficiency gained by creating an enclosed, ventilated attic space above the existing roof can provide additional benefit. As illustrated by the results of the ROI analysis for this application, it is advisable to perform a life-cycle cost/benefit study to determine the viability of this technology for a given project. There are guidance documents for evaluating

and developing slope conversion projects (Rosenfield and Doyle 1984; Sharp, Wendt, and McCorkle 1988).

5.1.3 FRP panel system

The demonstration showed that the use of durable FRP panel roofing to replace a failed metal roof can be beneficial for buildings that are not climate-controlled and where there is no ceiling to obstruct daylight transmission into the interior space. This technology can provide significant benefits, including better indoor lighting, improved thermal comfort, and lower energy bills, when used on buildings such as craft shops, warehouses, and industrial facilities.

5.2 Recommendations

5.2.1 Stone-coated metal shingle system with ASV

Analysis indicates that this technology is not at this time cost-effective in the application that was demonstrated. A substantial increase in benefit—possibly a very corrosion-prone environment where metal material performance is desired along with the aesthetics of asphalt shingles—combined with a significant reduction in cost would be necessary for this technology to be considered economical. The identified energy savings are much more pronounced in hot weather than in cold. Facilities in locales with a long cooling season would benefit more from this technology than ones located in a temperate climate.

Roof ASV designs should be further studied and assessed to determine energy benefits for particular applications. These should include their use in conjunction with different roofing materials, such as conventional asphalt shingles with varying reflection/emissivity properties.

5.2.2 Slope conversion using SSMR system with high-performance coating

Slope conversion with a corrosion-resistant SSMR should be considered only where there is a very clear extension of service life over a low-slope membrane system, including avoidance of ponding and excessive leakage. In general, it should also be considered only where a standard lightweight framing application can be used versus a purpose-engineered truss system like the one used in this demonstration. For roof replacement projects on smaller buildings with simple configurations, a life-cycle cost analysis

should be performed to determine project viability. When specifying an SSMR for slope conversion, designers and constructors must conform with the applicable Army and DoD criteria documents. The roof framing structure should be designed and/or approved by a licensed engineer.

5.2.3 FRP panel system

Translucent, UV-resistant FRP panel roofing should be considered as a roof replacement on buildings that are not climate-controlled and with no ceiling to obstruct daylight transmittal to the building interior. Typical applications would include maintenance shops and warehouses with conventional corrugated metal roofing. The FRP panel systems may be justified when daylighting can provide sufficient energy-use and productivity benefits.

Translucent FRP panel systems are not currently addressed in the Unified Facilities Criteria or Unified Facility Guide Specifications. It is recommended that the applicable criteria documents be revised to include use of this material where corrosion resistance, light weight, and translucence for daylighting purposes are specified.

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Appendix A: Roof Design Drawings for Buildings 8-3846 and 3-2631 (Stone-Coated Shingle System)

GENERAL NOTES:

1. BASIS OF DESIGN: NORTH CAROLINA STATE BUILDING CODE, 2006 EDITION.
   ASCE 7-02

   A. FLOOR LOADS: NO ALTERATION, EXISTING SLAB-ON-GRADE.

   B. ROOF LIVE LOAD: 20 PSF FOR NEW ROOF PANELS.
      EXISTING ROOF FRAMING 3:12 ROOF PITCH.

   C. GROUND SNOW LOAD: EXISTING ROOF SLOPE 3:12 PITCH. PLAN DIMENSIONS NOT CHANGED. Pg = 10PSF. BALANCED AND UNBALANCED SNOW LOADS ARE LESS THAN ROOF LIVE LOADS.

   D. WIND DESIGN DATA: SPEED: 100 MPH, 3-SECOND GUST.
      WIND IMPORTANCE FACTOR: IW = 1.0
      ENCLOSED BUILDING GCPI = +/- 0.18

      SEE SHEET S3 FOR WIND UPLIFT VALUES
      MWFRS - NO ALTERATIONS TO STRUCTURAL ELEMENTS. PARAGRAPH 1614.3.

   E. SEISMIC DESIGN DATA: NO ALTERATIONS TO STRUCTURAL ELEMENTS, PARAGRAPH 1614.3.

2. SCOPE OF WORK: INSTALL BATTEN AND SECOND LAYER DECKING TO SUPPORT NEW CORRSION RESISTANT SHINGLED ROOF WITH RELATED SOFFIT AND FACIA FINISHES. EXISTING FASCIA, GUTTER AND DOWNSPOUTS TO REMAIN, MINIMIZE DISTURBANCE. DAMAGE TO EXISTING FINISHES TO BE CORRECTED.

3. MATERIALS:

   A. ROOF SHINGLES: DECRA STONE COATED SHINGLE MANUFACTURED BY DECRA ROOFING SYSTEMS, INC. CORONA, CALIFORNIA.

      SHEET STEEL COMPLYING WITH ASTM A 792, GRADE 37, WITH AZ50 CLASS HOT-DIPPED ALUMINUM-ZINC ALLOY COATING.
      COATED STEEL THICKNESS: 0.017 INCH
      PANEL SIZE: 21 INCHES X 52 INCHES
      PANEL WEIGHT: ~ 1.25 PSF

      COLOR: FAWN GREY

      INSTALLER SHALL PROVIDE A WRITTEN WARRANTY FOR TWO (2) YEARS FROM THE DATE OF FINAL COMPLETION AND ACCEPTANCE, GUARANTEEING MATERIALS AND WORKMANSHIP FOR WATERTIGHTNESS, WEATHERTIGHTNESS, AND AGAINST ALL LEAKS. DURING THE INITIAL TWO (2) YEAR PERIOD. THE INSTALLER SHALL ASSURE WEATHERTIGHTNESS AND WATERTIGHTNESS OF THE ROOF WITHOUT ANY COST TO THE BUILDING OWNER.

   B. FLASHING AND TRIM ACCESSORIES: SHALL BE PROVIDED BY THE PANEL MANUFACTURER AND BE COMPATIBLE WITH AND THE SAME COLOR AS THE PROVIDED ROOF PANELS.

   C. BATTEN FRAMING:

      MEMBERS SHALL BE 4X2 SOUTHERN PINE OR MIXED SOUTHERN PINE, GRADE NO. 2 OR BETTER, UNLESS NOTED OTHERWISE.

   D. ROOF SHEATHING:

      SHEATHING SHALL BE MINIMUM 1/2" APA RATED SHEATHING, EXTERIOR PLYWOOD.

   E. FASTENERS:

      SCREWS SHALL BE SIZE AND LENGTH SHOWN ON DRAWINGS.

      WHERE NOT SPECIFIED, MINIMUM PENETRATION OF WOOD SCREW INTO MAIN MEMBER SHALL BE SIX TIMES THE DIAMETER.

      EDGE DISTANCES, END DISTANCES, AND SPACING SHALL BE SUFFICIENT TO PREVENT SPLITTING OF THE WOOD.

   F. CLOSURES AND SEALANTS:

      JOINT SEALANTS REQUIRED TO BE APPLIED BETWEEN SHORT CLOSURE CLIP AND METAL DRIP EDGE SHALL BE POLYURETHANE, SUCH AS SONNEBORN SONOLASTIC NP 1.

   G. PAINT FOR PENETRATION CURBS SHALL BE ARCHITECTURAL BROWN BY SHERWIN WILLIAMS

   H. MISCELLANEOUS METAL SHALL BE MINIMUM 24 GAGE STEEL MEETING ASTM A 792 ALUMINUM - ZINC ALLOY COATED WITH KYNAR 500 FINISH - COLOR DARK BRONZE

4. INSTALLATION:

   A. IDENTIFY EXISTING TRUSS CHORD LOCATIONS FOR PREPARATION OF ATTACHING BATTENS

      ATTACH 4X2 BATTENS OVER EXISTING SHINGLES TO EXISTING TRUSS CHORDS WITH SIZE, SPACING AND TYPE OF FASTENERS SHOWN ON THE DRAWINGS.

      ATTACH 1/2" ROOF SHEATHING TO BATTENS. FASTENER SIZE, SPACING AND TYPE SHALL BE AS SHOWN ON DRAWINGS. INSTALL SHEATHING WITH FACE GRAIN PERPENDICULAR TO SUPPORTS. LEAVE 1/8" SPACE BETWEEN ALL PANEL EDGE AND END JOINTS. INSTALL PANEL CLIPS AT PANEL EDGES SPANNING GREATER THAN 16 INCHES.

   B. UNDERLAYMENT SHALL BE INSTALLED AS FOLLOWS:

      UNDERLAYMENT SHALL BE TYPE I (#15) MEETING ASTM D 226 OR D 4869.

      APPLY ONE LAYER OF UNDERLAYMENT IN A SHINGLED FASHION STARTING PARALLEL TO THE EAVE AND LAPPING 2 INCHES. FASTEN AS NECESSARY TO HOLD IN PLACE.

   C. SHINGLE INSTALLATION

      COMPLY WITH MANUFACTURER'S PRODUCT DATA, TECHNICAL BULLETINS, AND INSTALLATION INSTRUCTIONS.

      INSTALL DRIP EDGE AND SHORT COURSE CLIP AT EAVE WITH FASENTERS AT 6" OC.

      INSTALL MODIFIED ROOF-TO-WALL CHANNEL ALONG HIP LOCATIONS. FASTEN AT 6" OC.

      FIELD PANELS: FIRST COURSE OF PANELS LOCK INTO THE EDGE CLIP. SUBSEQUENT COURSES OF PANELS LOCK INTO PLACE BY SLIDING THE NOSE OF EACH PANEL ONTO THE CLIP THAT IS FORMED AT THE TOP EDGE OF EACH PANEL. THE RIGHT SIDE OF EACH PANEL MUST BE COMPRESSED AND PUSHED INTO POSITION TO ENGAGE THE SIDE-LAP LOCKING MECHANISM. STAGGER SHINGLE PANELS AND INSTALL FROM RIGHT TO LEFT. STAGGER IS 25" EXPOSURE - 28" LENGTH. INSTALL FASTENERS IN PREDRILLED HOLES. WHEN INSTALLING PANELS, THE CLIP-LOCK ON THE LEFT WILL DROP DOWN APPROXIMATELY 1/4" TO 1/2" BELOW THE CLIP-LOCK ON THE RIGHT PANEL. THE MAXIMUM ALLOWABLE GAP BETWEEN PANELS SHOULD BE 3/16".

      RIDGE: RIDGE IS VENTED. FASTEN RIDGE SHINGLE THROUGH BACK CLIP WITH FASTENER OF SUFFICIENT LENGTH TO PASS THROUGH VENT MATERIAL AND THROUGH THE ROOF SHEATHING WITH 1/2" SCREW EXPOSED ON BACKSIDE OF SHEATHING.

   C. FASTENER INSTALLATION:

      CONTRACTOR'S QUALITY CONTROL PROGRAM SHALL MONITOR AND ENSURE SELF-TAPPING AND OTHER FASTENERS ARE INSTALLED TO THE PROPER TORQUE, SO AS TO PREVENT UNDER-TIGHTENING OR STRIPPING OUT OF SHEET METAL COMPONENTS.

REV	DESCRIPTION

BUILDING 3-2631
ROOF RENOVATIONS

CONTRACT NO:
W9132T-06-D-0001 08T0054

FORT BRAGG, NORTH CAROLINA

PENTA ENGINEERING GROUP, INC.
6755 Peachtree Industrial Blvd
Suite 150
Atlanta, Georgia 30360

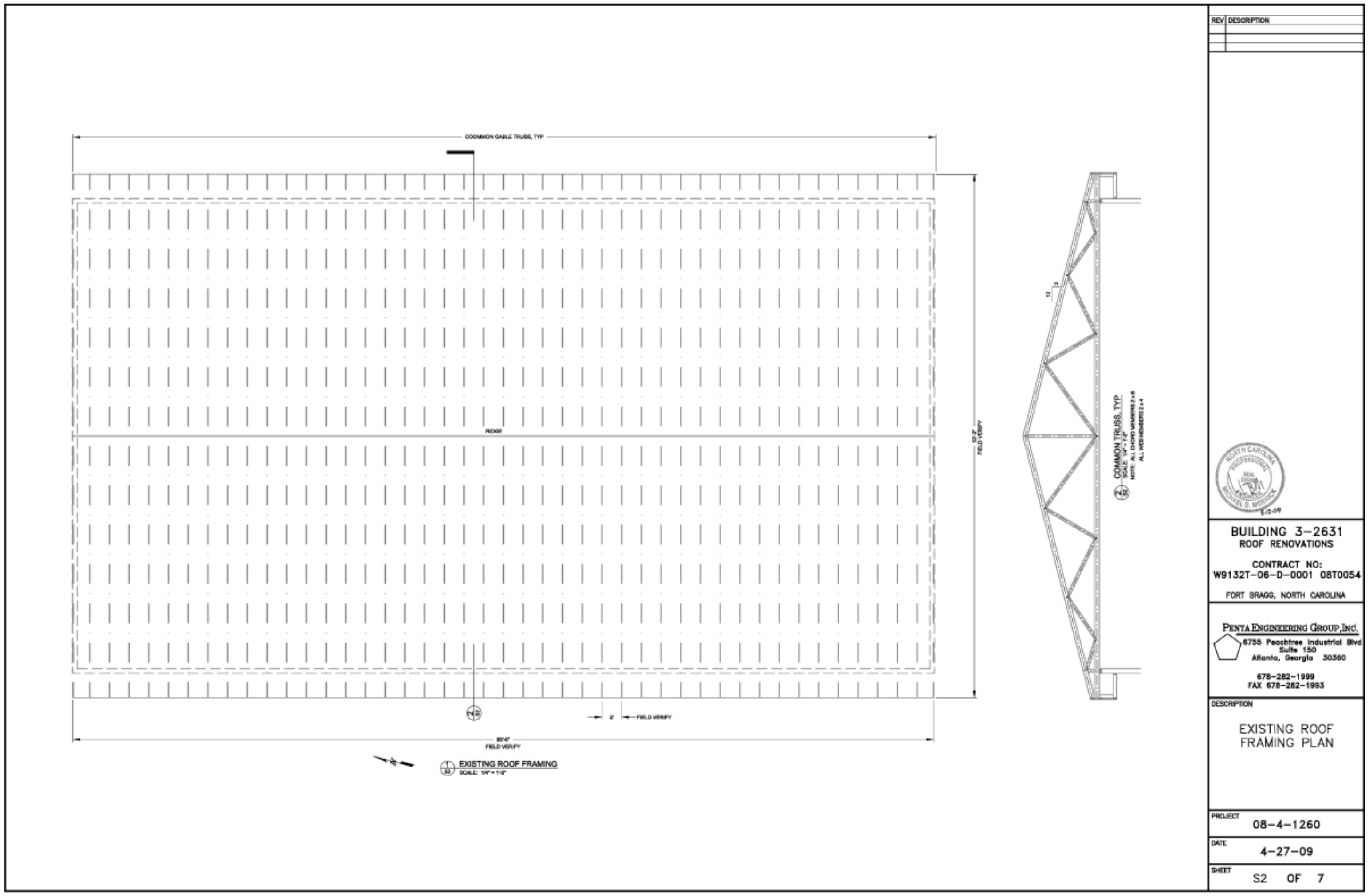
678-282-1999
FAX 678-282-1993

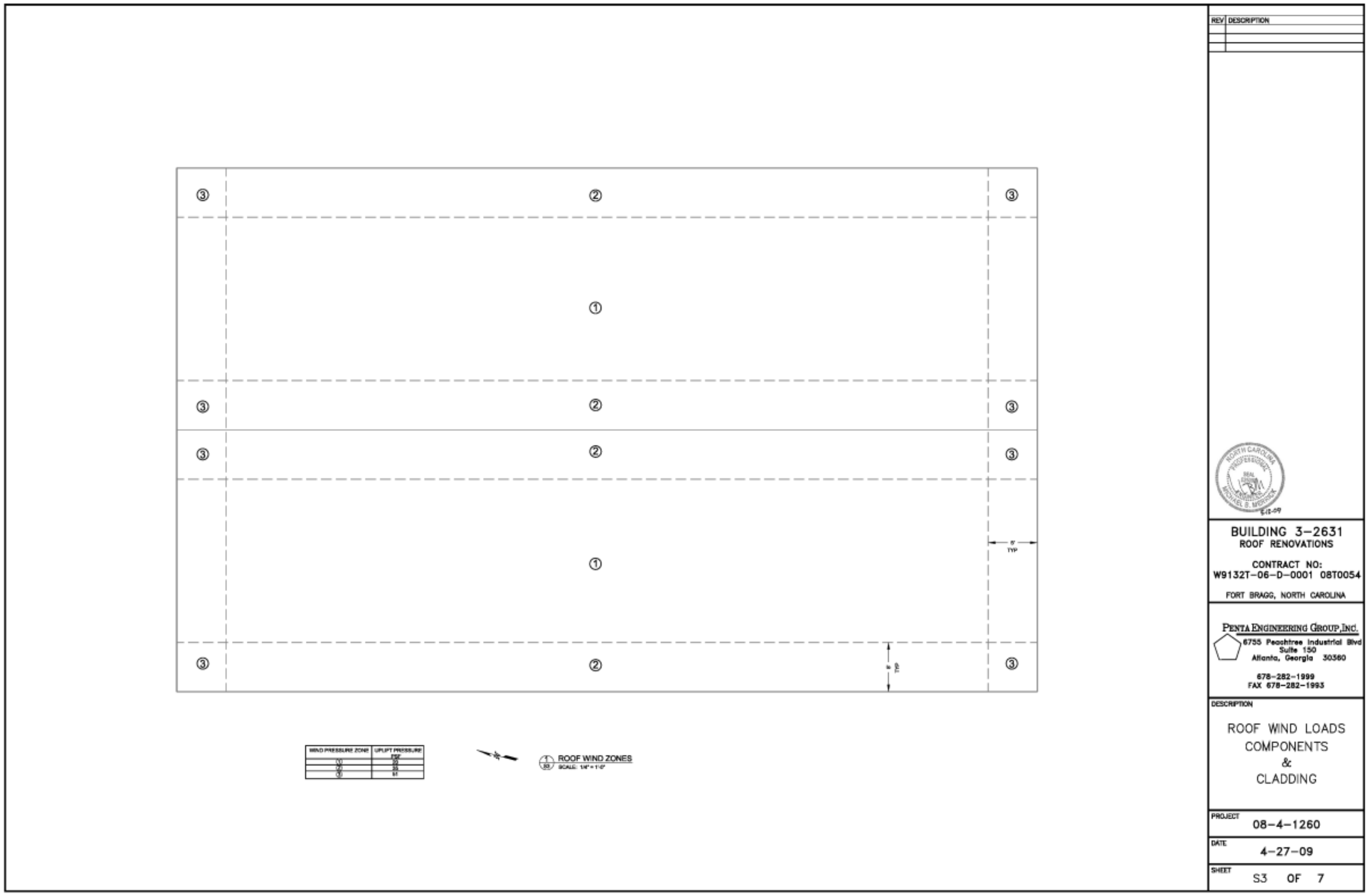
DESCRIPTION
GENERAL NOTES

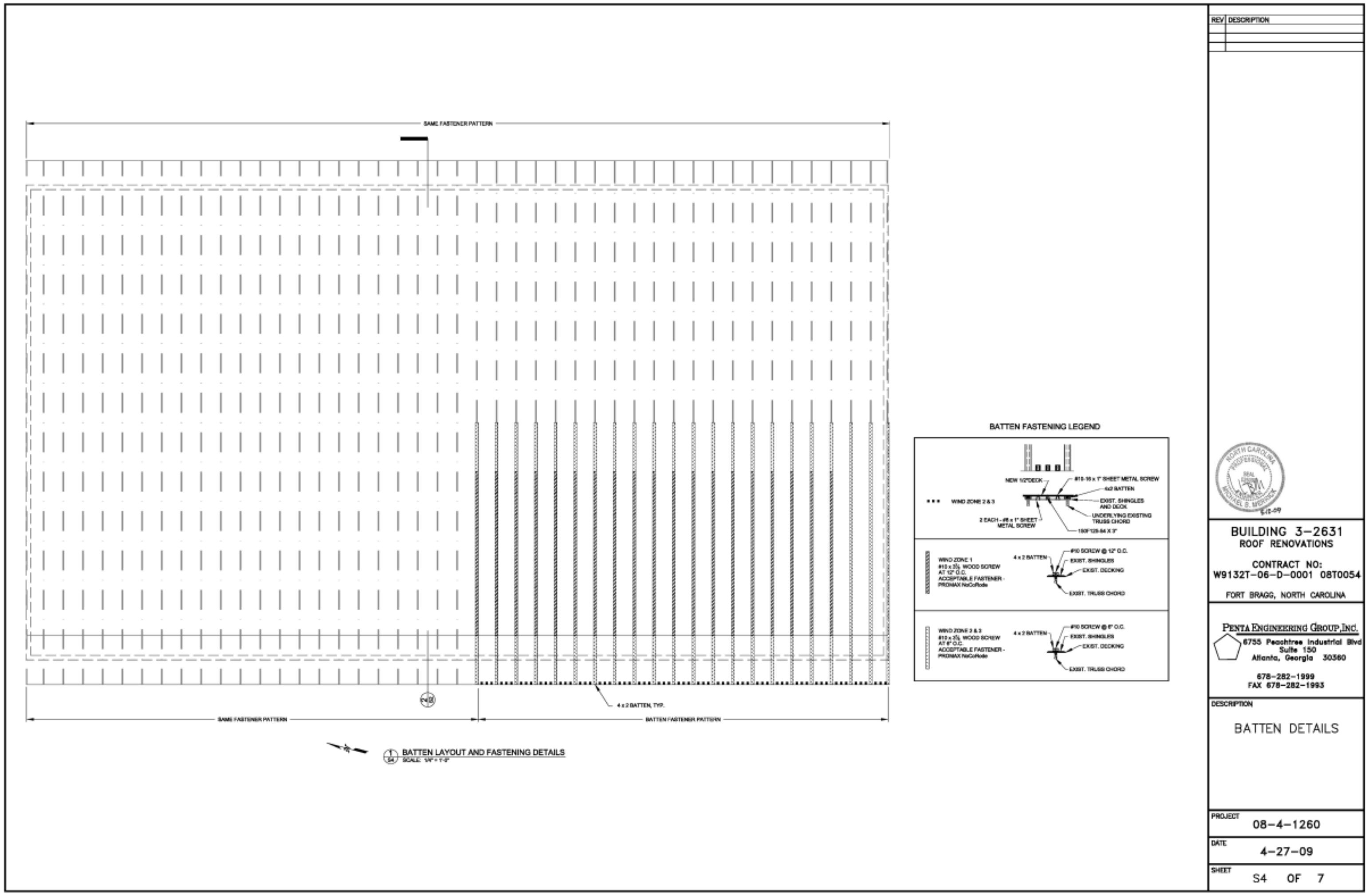
PROJECT 08-4-1260

DATE 4-27-09

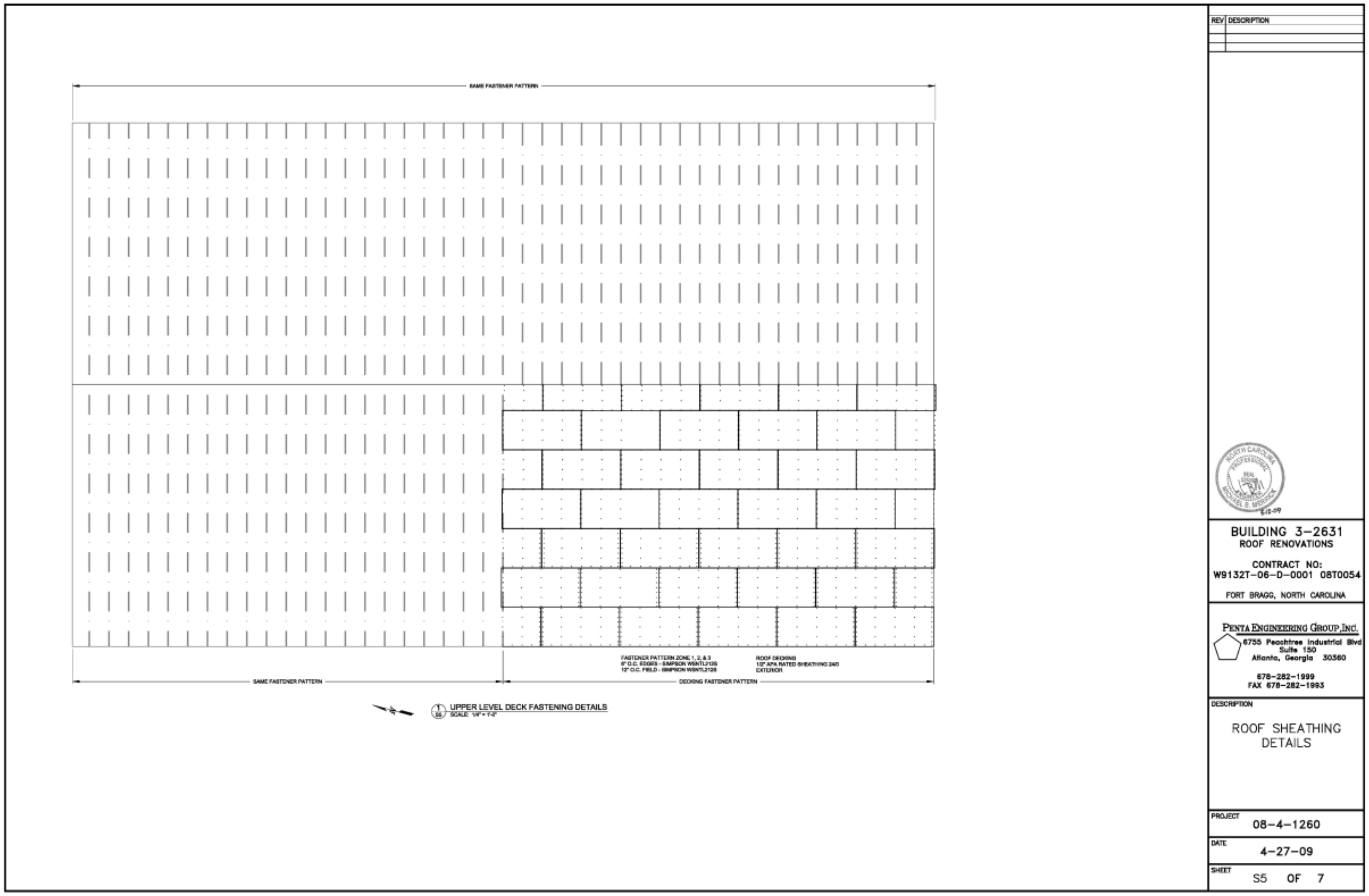
SHEET S1 OF 7


REV
DESCRIPTION
COMMON GABLE TRUSS, TYP
RIDGE
FIELD VERIFY
FIELD VERIFY
EXISTING ROOF FRAMING
COMMON TRUSS, TYP
BUILDING 3–2631
ROOF RENOVATIONS
CONTRACT NO:
W9132T–06–D–0001 08T0054
FORT BRAGG, NORTH CAROLINA
PENTA ENGINEERING GROUP, INC.
6755 Peachtree Industrial Blvd
Suite 150
Atlanta, Georgia 30360
678–282–1999
FAX 678–282–1993
DESCRIPTION
EXISTING ROOF
FRAMING PLAN
PROJECT
08–4–1260
DATE
4–27–09
SHEET
S2 OF 7


REV DESCRIPTION
BUILDING 3-2631
ROOF RENOVATIONS
CONTRACT NO:
W9132T-06-D-0001 08T0054
FORT BRAGG, NORTH CAROLINA
PENTA ENGINEERING GROUP, INC.
6755 Peachtree Industrial Blvd
Suite 150
Atlanta, Georgia 30360
678-282-1999
FAX 678-282-1993
DESCRIPTION
ROOF WIND LOADS
COMPONENTS
&
CLADDING
PROJECT
08-4-1260
DATE
4-27-09
SHEET
S3 OF 7
WIND PRESSURE ZONE
UPLIFT PRESSURE PSF
ROOF WIND ZONES
SCALE: 1/4" = 1'-0"
1
2
3



REV DESCRIPTION
SAME FASTENER PATTERN
SAME FASTENER PATTERN
BATTEN FASTENER PATTERN
4 x 2 BATTEN, TYP.
BATTEN LAYOUT AND FASTENING DETAILS
BATTEN FASTENING LEGEND
NEW 1/2"DECK
#10-16 x 1" SHEET METAL SCREW
4x2 BATTEN
WIND ZONE 2 & 3
EXIST. SHINGLES AND DECK
UNDERLYING EXISTING TRUSS CHORD
2 EACH - #8 x 1" SHEET METAL SCREW
WIND ZONE 1
#10 x 3½ WOOD SCREW
AT 12" O.C.
ACCEPTABLE FASTENER - PROMAX NoCoRode
4 x 2 BATTEN
#10 SCREW @ 12" O.C.
EXIST. SHINGLES
EXIST. DECKING
EXIST. TRUSS CHORD
WIND ZONE 2 & 3
#10 x 3½ WOOD SCREW
AT 6" O.C.
ACCEPTABLE FASTENER - PROMAX NoCoRode
4 x 2 BATTEN
#10 SCREW @ 6" O.C.
EXIST. SHINGLES
EXIST. DECKING
EXIST. TRUSS CHORD
NORTH CAROLINA PROFESSIONAL SEAL ENGINEER MICHAEL B. MERRICK
BUILDING 3-2631
ROOF RENOVATIONS
CONTRACT NO:
W9132T-06-D-0001 08T0054
FORT BRAGG, NORTH CAROLINA
PENTA ENGINEERING GROUP, INC.
6755 Peachtree Industrial Blvd
Suite 150
Atlanta, Georgia 30360
678-282-1999
FAX 678-282-1993
DESCRIPTION
BATTEN DETAILS
PROJECT
08-4-1260
DATE
4-27-09
SHEET
S4 OF 7


SAME FASTENER PATTERN
SAME FASTENER PATTERN
FASTENER PATTERN ZONE 1, 2, & 3
6" O.C. EDGES - SIMPSON WSNTL2126
12" O.C. FIELD - SIMPSON WSNTL2126
ROOF DECKING
1/2" APA RATED SHEATHING 24/0
EXTERIOR
DECKING FASTENER PATTERN
UPPER LEVEL DECK FASTENING DETAILS
REV
DESCRIPTION
BUILDING 3-2631
ROOF RENOVATIONS
CONTRACT NO:
W9132T-06-D-0001 08T0054
FORT BRAGG, NORTH CAROLINA
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6755 Peachtree Industrial Blvd
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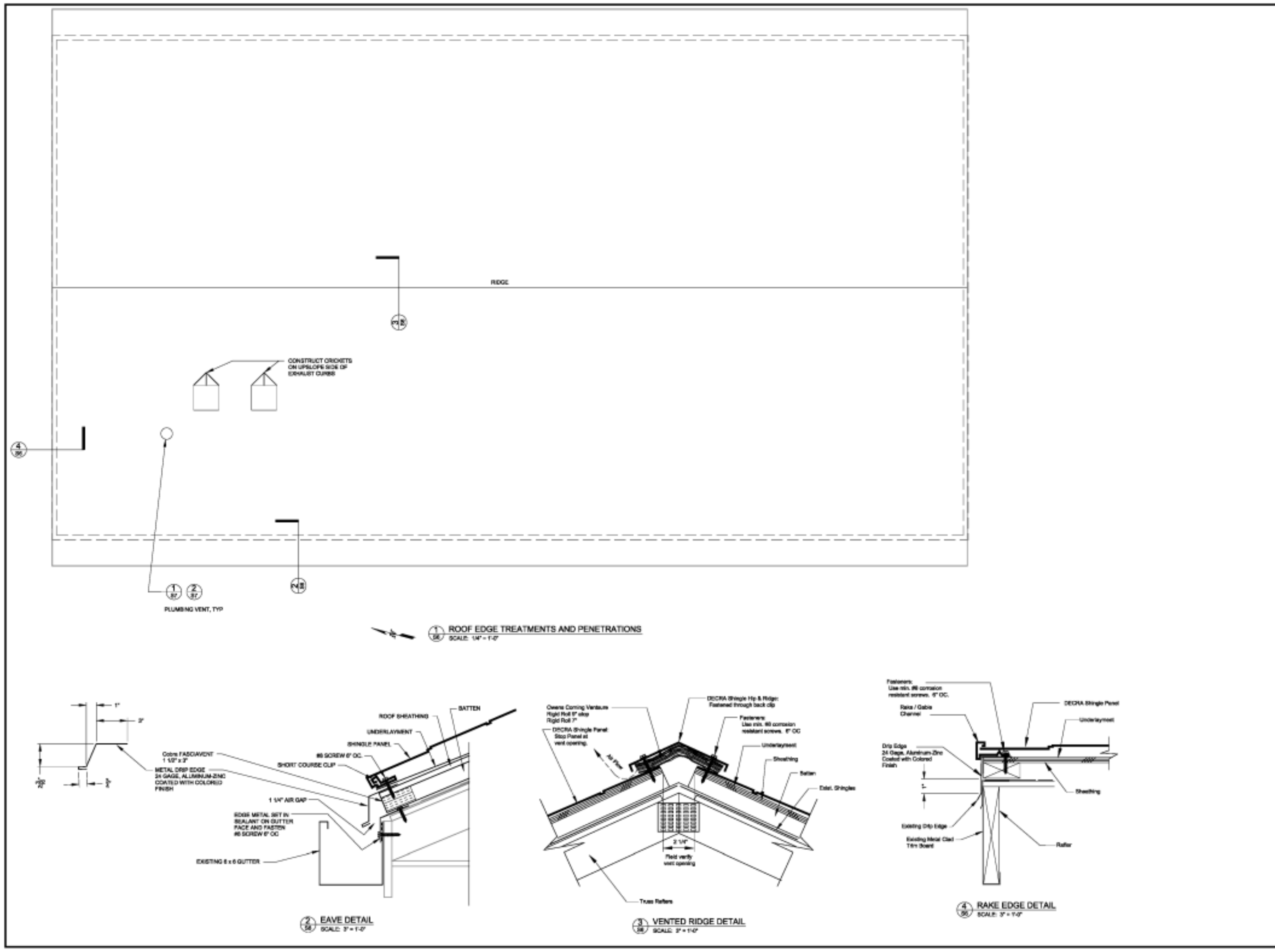
678-282-1999
FAX 678-282-1993
DESCRIPTION
ROOF SHEATHING DETAILS
PROJECT
08-4-1260
DATE
4-27-09
SHEET
S5 OF 7



REV	DESCRIPTION

NORTH CAROLINA PROFESSIONAL ENGINEER SEAL MICHAEL B. MERRICK
6-12-09

BUILDING 3-2631
ROOF RENOVATIONS

CONTRACT NO:
W9132T-06-D-0001 08T0054

FORT BRAGG, NORTH CAROLINA

PENTA ENGINEERING GROUP, INC.
6755 Peachtree Industrial Blvd
Suite 150
Atlanta, Georgia 30360

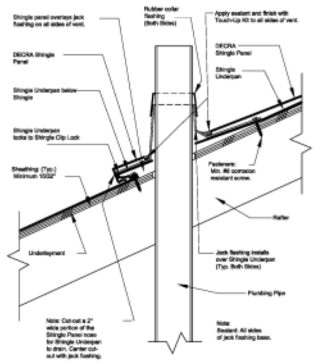
678-282-1999
FAX 678-282-1993

DESCRIPTION
GUTTER AND
DOWNSPOUT
EAVE VENT DETAILS

PROJECT 08-4-1260

DATE 4-27-09

SHEET S6 OF 7



1/S7 VENT FLASHING DETAIL
SCALE: 3" = 1'-0"

Step (1) - Cut-out the required vent opening into the roof deck and Shingle Underpan. Allow a 1/4" gap around the vent pipe when cutting the Shingle Underpan opening, and use care to not oversize the opening.

Step (2) - Place the Shingle Underpan over the vent pipe and Underlayment. Place the vertical nose of the Shingle Underpan over the Clip Lock at the back of the Shingle Panel on the low side of the vent pipe. Push the Shingle Underpan nose against the Clip Lock, and secure the upper end of the Shingle Underpan to the roof deck.

Step (3) - Place the Jack Flashing over the vent pipe and Shingle Underpan. Fasten Jack Flashing to the Shingle Underpan at the high side of its base. Install sealant continuous around the Jack Flashing Base.

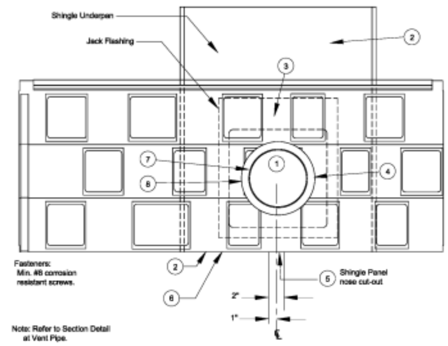
Step (4) - Cut-out the required vent opening into the DECRA Shingle Panel. Allow a gap around the vent Jack Flashing when cutting the Shingle Panel opening, for positioning and locking the Shingle Panel in place. Use care to not oversize the opening.

Step (5) - Cut-out a 2" wide notch in the nosing of the DECRA Shingle Panel to be placed over the vent pipe, to allow for Shingle Underpan drainage. Center the nosing cut-out with the Jack Flashing.

Step (6) - Place the cut-out DECRA Shingle Panel over the Jack Flashing, and position it into place. Install the Shingle Panel nosing under the Clip Lock of the lower panel, and secure the top of the Shingle Panel to the roof deck.

Step (7) - Install a rubber storm collar over the vent pipe, and lap it over the top of Jack Flashing for 3/4".

Step (8) - Install sealant continuous around the DECRA Shingle Panel vent opening, and finish the installation with DECRA Touch-Up Kit.



Note: Refer to Section Detail at Vent Pipe.

2/S7 VENT FLASHING INSTALLATION
SCALE: 1 1/2" = 1'-0"

REV	DESCRIPTION

BUILDING 3-2631
ROOF RENOVATIONS

CONTRACT NO:
W9132T-06-D-0001 08T0054

FORT BRAGG, NORTH CAROLINA

PENTA ENGINEERING GROUP, INC.
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678-282-1999
FAX 678-282-1993

DESCRIPTION
SECTIONS & DETAILS

PROJECT 08-4-1260

DATE 4-27-09

SHEET S7 OF 7

GENERAL NOTES:

1. BASIS OF DESIGN: NORTH CAROLINA STATE BUILDING CODE, 2006 EDITION.
ASCE 7-02

A. FLOOR LOADS: NO ALTERATION, EXISTING SLAB-ON-GRADE.

B. ROOF LIVE LOAD: 16 PSF FOR NEW ROOF PANELS.

C. GROUND SNOW LOAD: EXISTING ROOF SLOPE 5:12 PITCH. PLAN DIMENSIONS NOT CHANGED. Pg = 10PSF. BALANCED AND UNBALANCED SNOW LOADS ARE LESS THAN ROOF LIVE LOADS.

D. WIND DESIGN DATA: SPEED: 100 MPH, 3-SECOND GUST.
WIND IMPORTANCE FACTOR: IW = 1.0
ENCLOSED BUILDING GCPI = +/- 0.18

SEE SHEET S3 FOR WIND UPLIFT VALUES
MWFRS - NO ALTERATIONS TO STRUCTURAL ELEMENTS. PARAGRAPH 1614.3.

E. SEISMIC DESIGN DATA: NO ALTERATIONS TO STRUCTURAL ELEMENTS, PARAGRAPH 1614.3.

2. SCOPE OF WORK: INSTALL BATTEN AND SECOND LAYER DECKING TO SUPPORT NEW CORRSION RESISTANT SHINGLED ROOF WITH GUTTERS, DOWNSPOUTS AND RELATED SOFFIT AND FACIA FINISHES.

3. MATERIALS:

A. ROOF SHINGLES: DECRA STONE COATED SHINGLE MANUFACTURED BY DECRA ROOFING SYSTEMS, INC. CORONA, CALIFORNIA.

SHEET STEEL COMPLYING WITH ASTM A 792, GRADE 37, WITH AZ50 CLASS HOT-DIPPED
ALUMINUM-ZINC ALLOY COATING.
COATED STEEL THICKNESS: 0.017 INCH
PANEL SIZE: 21 INCHES X 52 INCHES
PANEL WEIGHT: ~ 1.25 PSF

COLOR: FAWN GREY

INSTALLER SHALL PROVIDE A WRITTEN WARRANTY FOR TWO (2) YEARS FROM THE DATE OF FINAL COMPLETION AND ACCEPTANCE, GUARANTEEING MATERIALS AND WORKMANSHIP FOR WATERTIGHTNESS, WEATHERTIGHTNESS, AND AGAINST ALL LEAKS. DURING THE INITIAL TWO (2) YEAR PERIOD, THE INSTALLER SHALL ASSURE WEATHERTIGHTNESS AND WATERTIGHTNESS OF THE ROOF WITHOUT ANY COST TO THE BUILDING OWNER.

B. FLASHING AND TRIM ACCESSORIES: SHALL BE PROVIDED BY THE PANEL MANUFACTURER AND BE COMPATIBLE WITH AND THE SAME COLOR AS THE PROVIDED ROOF PANELS.

C. BATTEN FRAMING:

MEMBERS SHALL BE 4X2 SOUTHERN PINE OR MIXED SOUTHERN PINE, GRADE NO. 2 OR BETTER, UNLESS NOTED OTHERWISE.

D. ROOF SHEATHING:

SHEATHING SHALL BE MINIMUM 5/8" APA RATED SHEATHING, EXTERIOR PLYWOOD.

E. FASTENERS:

SCREWS SHALL BE SIZE AND LENGTH SHOWN ON DRAWINGS.

WHERE NOT SPECIFIED, MINIMUM PENETRATION OF WOOD SCREW INTO MAIN MEMBER SHALL BE SIX TIMES THE DIAMETER.

EDGE DISTANCES, END DISTANCES, AND SPACING SHALL BE SUFFICIENT TO PREVENT SPLITTING OF THE WOOD.

F. CLOSURES AND SEALANTS:

JOINT SEALANTS REQUIRED TO BE APPLIED BETWEEN SHORT CLOSURE CLIP AND METAL DRIP EDGE SHALL BE POLYURETHANE, SUCH AS SONNEBORN SONOLASTIC NP 1 .

G. PAINT FOR PENETRATION CURBS SHALL BE ARCHITECTURAL BROWN BY SHERWIN WILLIAMS

H. MISCELLANEOUS METAL SHALL BE MINIMUM 24 GAGE STEEL MEETING ASTM A 792
ALUMINUM - ZINC ALLOY COATED WITH KYNAR FINISH - COLOR DARK BRONZE

4. INSTALLATION:

A. IDENTIFY EXISTING TRUSS CHORD LOCATIONS FOR PREPARATION OF ATTACHING BATTENS

ATTACH 4X2 BATTENS OVER EXISTING SHINGLES TO EXISTING TRUSS CHORDS WITH SIZE, SPACING AND TYPE OF FASTENERS SHOWN ON THE DRAWINGS.

ATTACH 5/8" ROOF SHEATHING TO BATTENS. FASTENER SIZE, SPACING AND TYPE SHALL BE AS SHOWN ON DRAWINGS. INSTALL SHEATHING WITH FACE GRAIN PERPENDICULAR TO SUPPORTS. LEAVE 1/8" SPACE BETWEEN ALL PANEL EDGE AND END JOINTS. INSTALL PANEL CLIPS AT PANEL EDGES SPANNING GREATER THAN 16 INCHES.

B. UNDERLAYMENT SHALL BE INSTALLED AS FOLLOWS:

UNDERLAYMENT SHALL BE TYPE I (#15) MEETING ASTM D 226 OR D 4869.

APPLY ONE LAYER OF UNDERLAYMENT IN A SHINGLED FASHION STARTING PARALLEL TO THE EAVE AND LAPPING 2 INCHES. FASTEN AS NECESSARY TO HOLD IN PLACE.

C. SHINGLE INSTALLATION

COMPLY WITH MANUFACTURER'S PRODUCT DATA, TECHNICAL BULLETINS, AND INSTALLATION INSTRUCTIONS.

INSTALL DRIP EDGE AND SHORT COURSE CLIP AT EAVE WITH FASENTERS AT 6" OC.

INSTALL MODIFIED ROOF-TO-WALL CHANNEL ALONG HIP LOCATIONS. FASTEN AT 6" OC.

FIELD PANELS: FIRST COURSE OF PANELS LOCK INTO THE EDGE CLIP. SUBSEQUENT COURSES OF PANELS LOCK INTO PLACE BY SLIDING THE NOSE OF EACH PANEL ONTO THE CLIP THAT IS FORMED AT THE TOP EDGE OF EACH PANEL. THE RIGHT SIDE OF EACH PANEL MUST BE COMPRESSED AND PUSHED INTO POSITION TO ENGAGE THE SIDE-LAP LOCKING MECHANISM. STAGGER SHINGLE PANELS AND INSTALL FROM RIGHT TO LEFT. STAGGER IS 25" EXPOSURE - 28" LENGTH. INSTALL FASTENERS IN PREDRILLED HOLES. WHEN INSTALLING PANELS, THE CLIP-LOCK ON THE LEFT WILL DROP DOWN APPROXIMATELY 1/4" TO 1/2" BELOW THE CLIP-LOCK ON THE RIGHT PANEL. THE MAXIMUM ALLOWABLE GAP BETWEEN PANELS SHOULD BE 3/16".

HIP AND RIDGE: BOTH HIP AND RIDGE ARE VENTED. FASTEN HIP AND RIDGE SHINGLE THROUGH BACK CLIP WITH FASTENER OF SUFFICIENT LENGTH TO PASS THROUGH VENT MATERIAL AND THROUGH THE ROOF SHEATHING WITH 1/2" SCREW EXPOSED ON BACKSIDE OF SHEATHING.

C. FASTENER INSTALLATION:

CONTRACTOR'S QUALITY CONTROL PROGRAM SHALL MONITOR AND ENSURE SELF-TAPPING AND OTHER FASTENERS ARE INSTALLED TO THE PROPER TORQUE, SO AS TO PREVENT UNDER-TIGHTENING OR STRIPPING OUT OF SHEET METAL COMPONENTS.

REV	DESCRIPTION

BUILDING 8–3846
ROOF RENOVATIONS

CONTRACT NO:
W9132T–06–D–0001 08T0054

FORT BRAGG, NORTH CAROLINA

PENTA ENGINEERING GROUP, INC.
6755 Peachtree Industrial Blvd
Suite 150
Atlanta, Georgia 30360

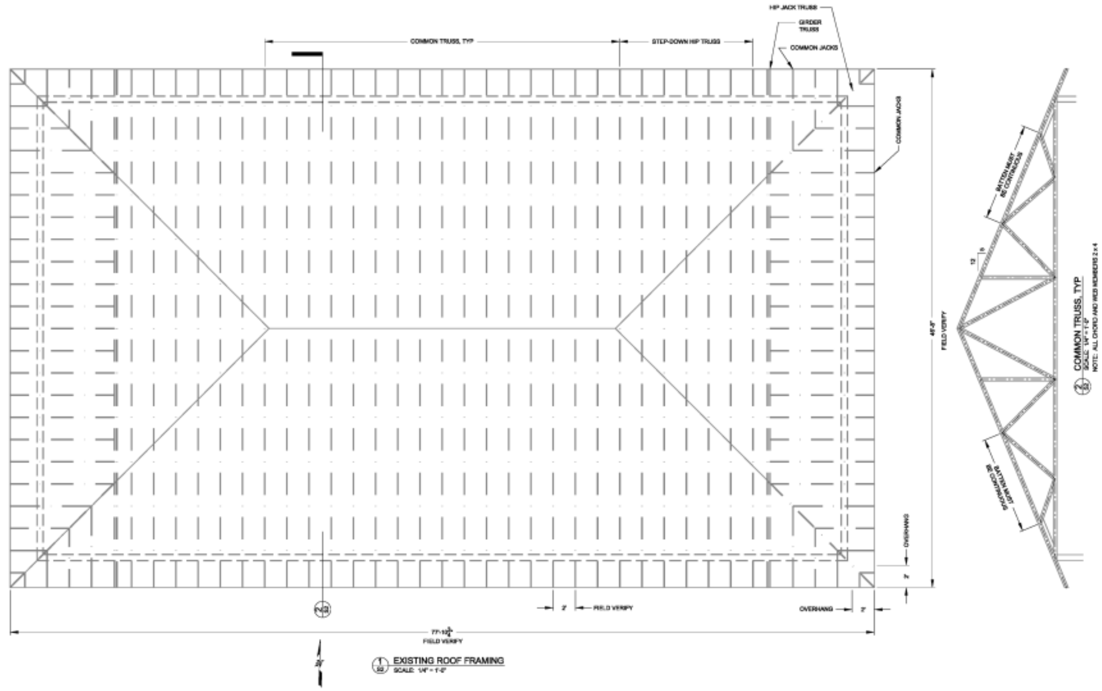
678–282–1999
FAX 678–282–1993

DESCRIPTION
GENERAL NOTES

PROJECT 08–4–1260

DATE 4–27–09

SHEET S1 OF 7



REV	DESCRIPTION

BUILDING 8-3846
ROOF RENOVATIONS

CONTRACT NO:
W9132T-06-D-0001 08T0054

FORT BRAGG, NORTH CAROLINA

PENTA ENGINEERING GROUP, INC.
6755 Peachtree Industrial Blvd
Suite 150
Atlanta, Georgia 30360

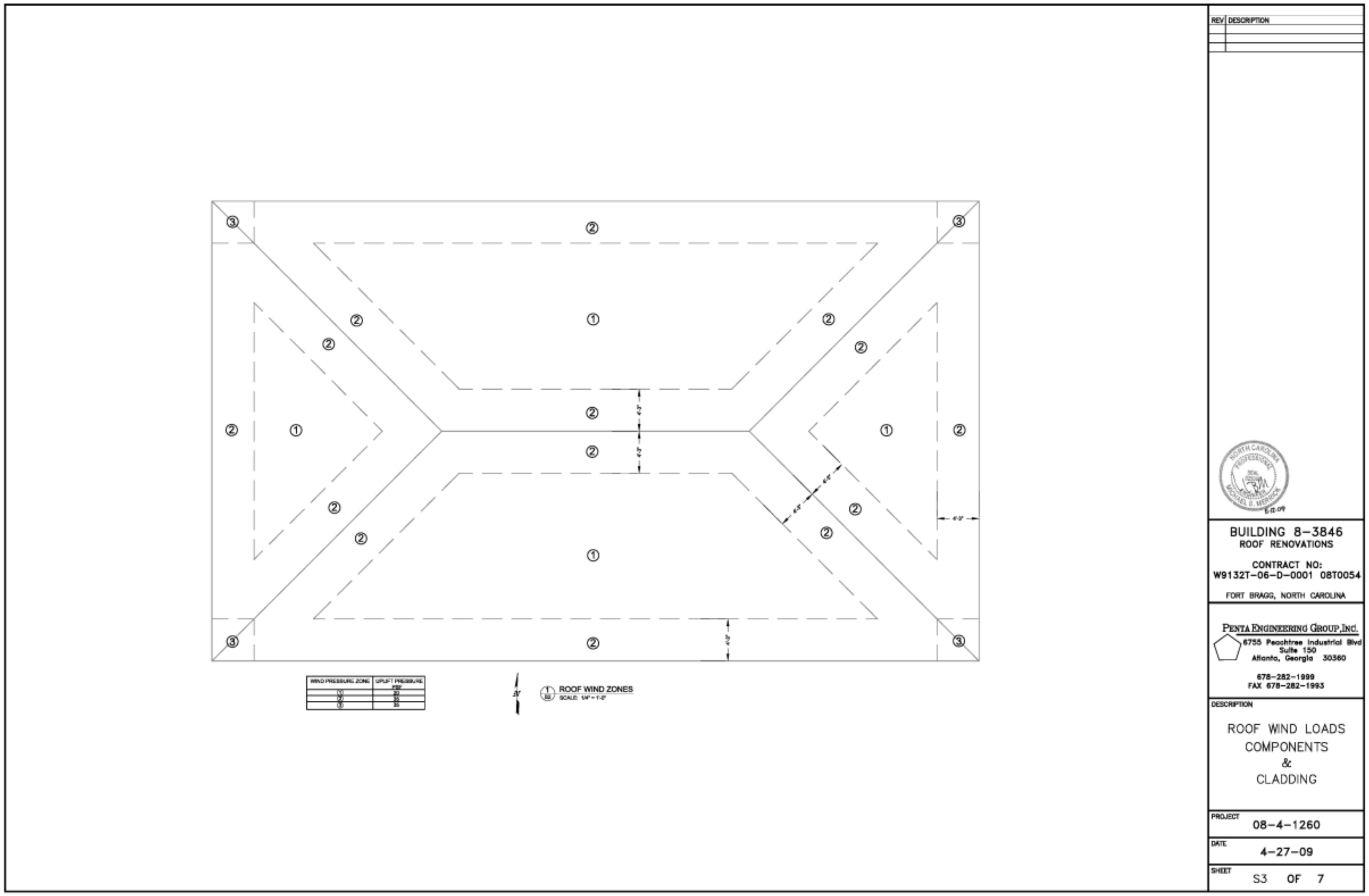
678-282-1999
FAX 678-282-1993

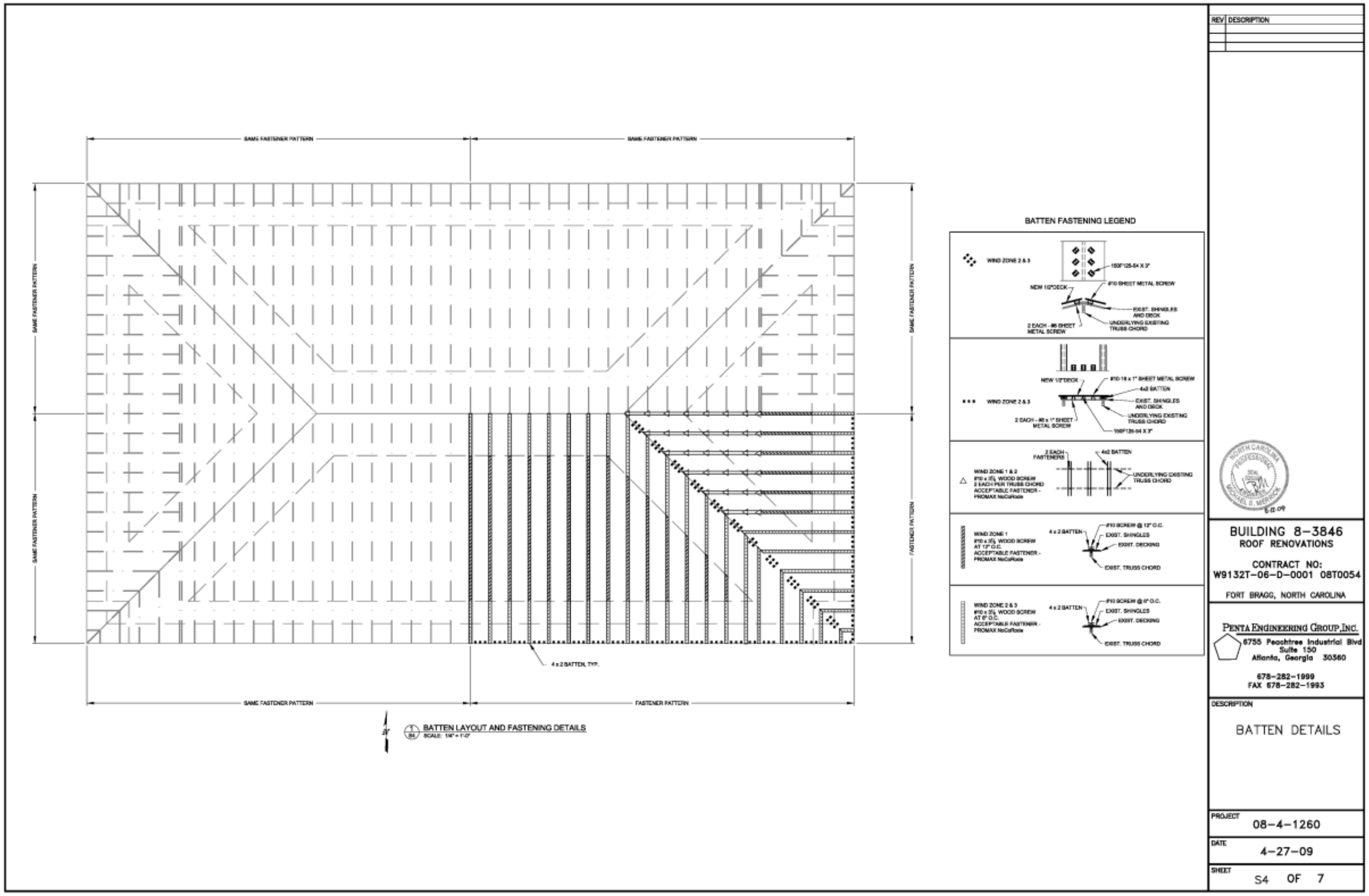
DESCRIPTION
EXISTING ROOF FRAMING PLAN

PROJECT 08-4-1260

DATE 4-27-09

SHEET S2 OF 7


ROOF WIND ZONES
SCALE: 1/4" = 1'-0"
WIND PRESSURE ZONE | UPLIFT PRESSURE PSF
1 | 20
2 | 35
3 | 35
REV DESCRIPTION
BUILDING 8-3846
ROOF RENOVATIONS
CONTRACT NO:
W9132T-06-D-0001 08T0054
FORT BRAGG, NORTH CAROLINA
PENTA ENGINEERING GROUP, INC.
6755 Peachtree Industrial Blvd
Suite 150
Atlanta, Georgia 30360
678-282-1999
FAX 678-282-1993
DESCRIPTION
ROOF WIND LOADS
COMPONENTS
&
CLADDING
PROJECT
08-4-1260
DATE
4-27-09
SHEET
S3 OF 7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SAME FASTENER PATTERN
SAME FASTENER PATTERN
SAME FASTENER PATTERN
FASTENER PATTERN
4 x 2 BATTEN, TYP.
BATTEN LAYOUT AND FASTENING DETAILS
SCALE: 1/4" = 1'-0"
BATTEN FASTENING LEGEND
WIND ZONE 2 & 3
NEW 1/2"DECK
#10 SHEET METAL SCREW
EXIST. SHINGLES AND DECK
UNDERLYING EXISTING TRUSS CHORD
2 EACH - #8 SHEET METAL SCREW
WIND ZONE 2 & 3
NEW 1/2"DECK
#10-16 x 1" SHEET METAL SCREW
4x2 BATTEN
EXIST. SHINGLES AND DECK
UNDERLYING EXISTING TRUSS CHORD
2 EACH - #8 x 1" SHEET METAL SCREW
2 EACH FASTENERS
4x2 BATTEN
WIND ZONE 1 & 2
#10 x 3½ WOOD SCREW
2 EACH PER TRUSS CHORD
ACCEPTABLE FASTENER - PROMAX NoCaRode
UNDERLYING EXISTING TRUSS CHORD
WIND ZONE 1
#10 x 3½ WOOD SCREW AT 12" O.C.
ACCEPTABLE FASTENER - PROMAX NoCaRode
4 x 2 BATTEN
#10 SCREW @ 12" O.C.
EXIST. SHINGLES
EXIST. DECKING
EXIST. TRUSS CHORD
WIND ZONE 2 & 3
#10 x 3½ WOOD SCREW AT 6" O.C.
ACCEPTABLE FASTENER - PROMAX NoCaRode
4 x 2 BATTEN
#10 SCREW @ 6" O.C.
EXIST. SHINGLES
EXIST. DECKING
EXIST. TRUSS CHORD
BUILDING 8-3846
ROOF RENOVATIONS
CONTRACT NO:
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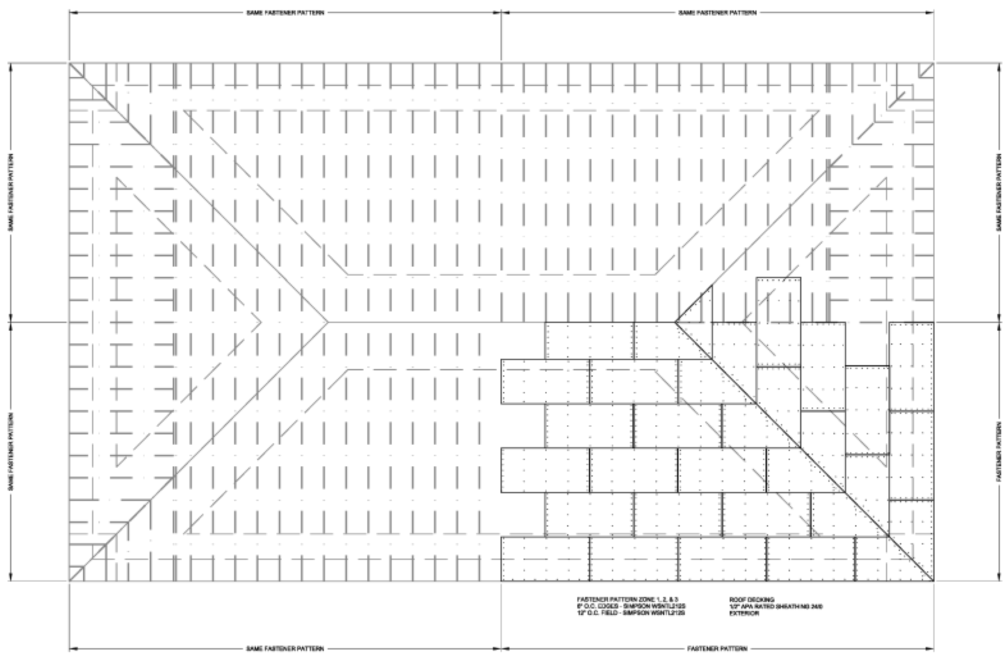
Atlanta, Georgia 30360
678-282-1999
FAX 678-282-1993
DESCRIPTION
BATTEN DETAILS
PROJECT
08-4-1260
DATE
4-27-09
SHEET
S4 OF 7



UPPER LEVEL DECK FASTENING DETAILS

REV	DESCRIPTION

BUILDING 8–3846
ROOF RENOVATIONS

CONTRACT NO:
W9132T–06–D–0001 08T0054

FORT BRAGG, NORTH CAROLINA

PENTA ENGINEERING GROUP, INC.
6755 Peachtree Industrial Blvd
Suite 150
Atlanta, Georgia 30360

678–282–1999
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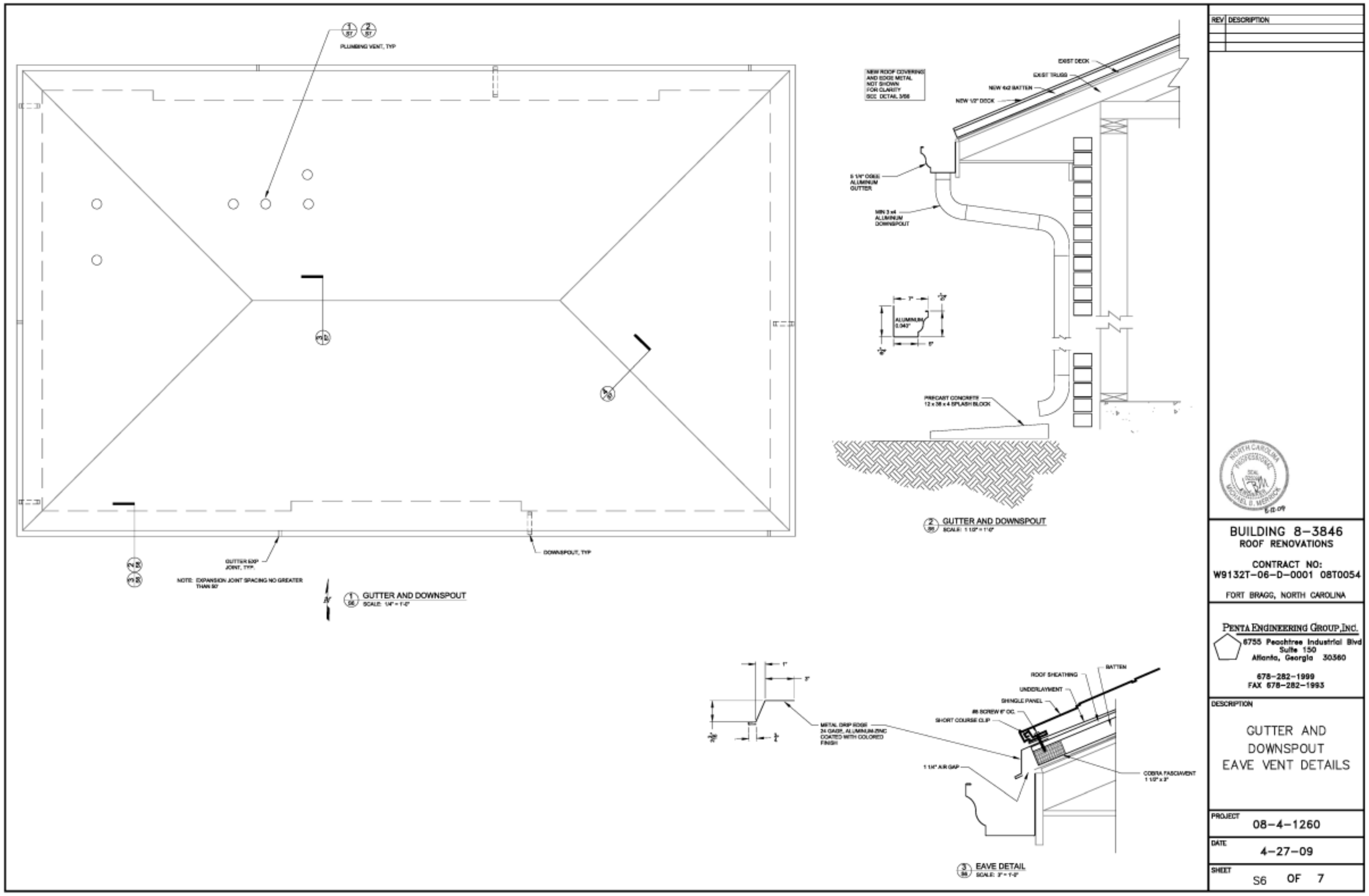
DESCRIPTION

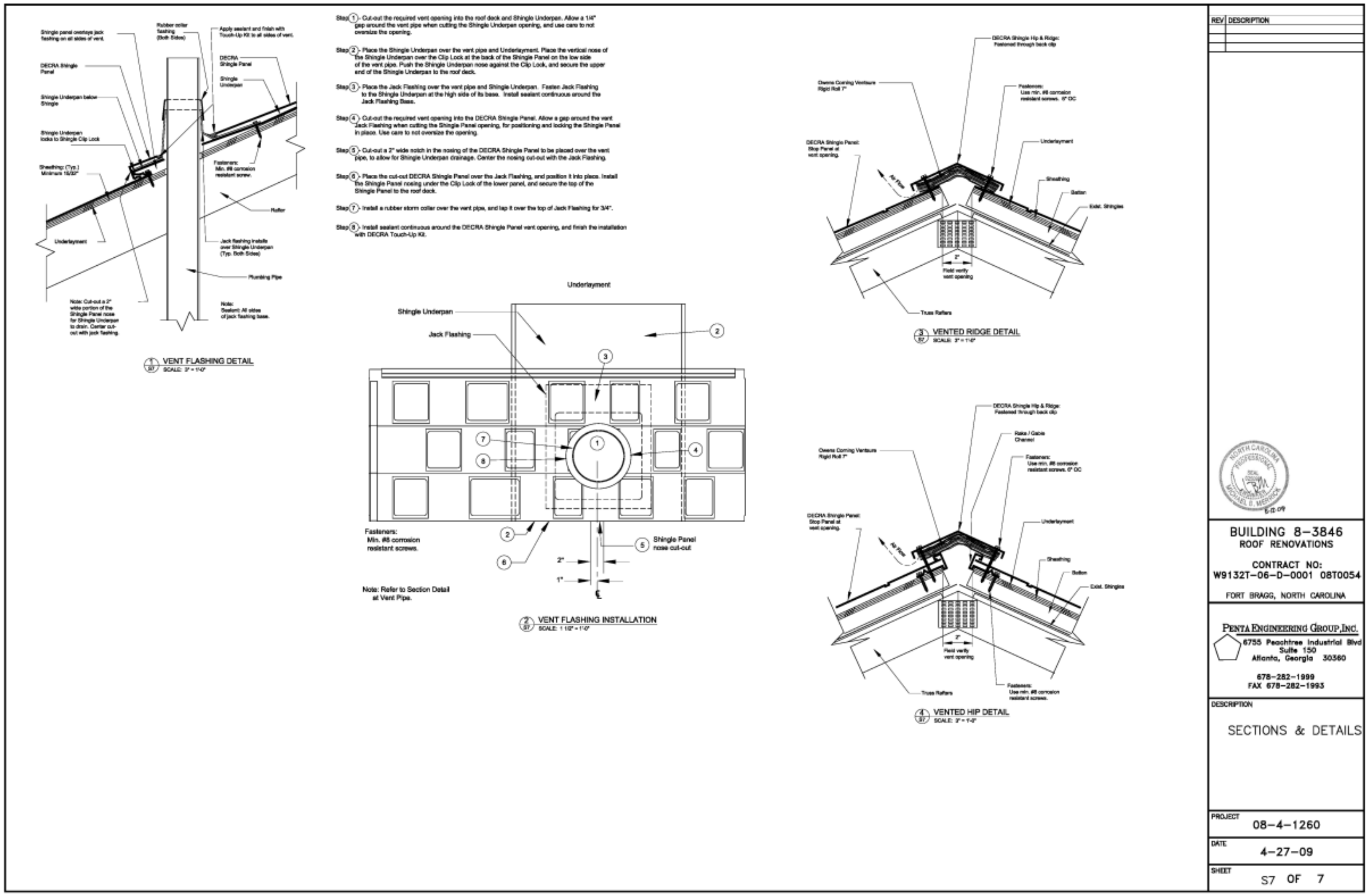
ROOF SHEATHING DETAILS

PROJECT 08–4–1260

DATE 4–27–09

SHEET S5 OF 7


PLUMBING VENT, TYP
NEW ROOF COVERING AND EDGE METAL NOT SHOWN FOR CLARITY SEE DETAIL 3/S6
EXIST DECK
EXIST TRUSS
NEW 4x2 BATTEN
NEW 1/2" DECK
ALUMINUM GUTTER
MIN 3 x4 ALUMINUM DOWNSPOUT
ALUMINUM 0.040"
PRECAST CONCRETE 12 x 36 x 4 SPLASH BLOCK
GUTTER EXP JOINT, TYP.
DOWNSPOUT, TYP
NOTE: EXPANSION JOINT SPACING NO GREATER THAN 50'
GUTTER AND DOWNSPOUT
SCALE: 1/4" = 1'-0"
GUTTER AND DOWNSPOUT
ROOF SHEATHING
BATTEN
UNDERLAYMENT
SHINGLE PANEL
SHORT COURSE CLIP
METAL DRIP EDGE 24 GAGE, ALUMINUM-ZINC COATED WITH COLORED FINISH
1 1/4" AIR GAP
COBRA FASCIAVENT
EAVE DETAIL
REV DESCRIPTION
BUILDING 8-3846
ROOF RENOVATIONS
CONTRACT NO:
W9132T-06-D-0001 08T0054
FORT BRAGG, NORTH CAROLINA
PENTA ENGINEERING GROUP, INC.
5755 Peachtree Industrial Blvd
Suite 150
Atlanta, Georgia 30360
678-282-1999
FAX 678-282-1993
DESCRIPTION
GUTTER AND
DOWNSPOUT
EAVE VENT DETAILS
PROJECT
08-4-1260
DATE
4-27-09
SHEET
S6 OF 7


Shingle panel overlays jack flashing on all sides of vent.
Rubber collar flashing (Both Sides)
Apply sealant and finish with Touch-Up Kit to all sides of vent.
DECRA Shingle Panel
Shingle Underpan below Shingle
Shingle Underpan
Shingle Underpan locks to Shingle Clip Lock
Sheathing: (Typ.) Minimum 15/32"
Fasteners: Min. #8 corrosion resistant screw.
Rafter
Underlayment
Jack flashing installs over Shingle Underpan (Typ. Both Sides)
Plumbing Pipe
Note: Cut-out a 2" wide portion of the Shingle Panel nose for Shingle Underpan to drain. Center cut-out with jack flashing.
Note: Sealant: All sides of jack flashing base.
1 S7 VENT FLASHING DETAIL
SCALE: 3" = 1'-0"
Step 1 - Cut-out the required vent opening into the roof deck and Shingle Underpan. Allow a 1/4" gap around the vent pipe when cutting the Shingle Underpan opening, and use care to not oversize the opening.
Step 2 - Place the Shingle Underpan over the vent pipe and Underlayment. Place the vertical nose of the Shingle Underpan over the Clip Lock at the back of the Shingle Panel on the low side of the vent pipe. Push the Shingle Underpan nose against the Clip Lock, and secure the upper end of the Shingle Underpan to the roof deck.
Step 3 - Place the Jack Flashing over the vent pipe and Shingle Underpan. Fasten Jack Flashing to the Shingle Underpan at the high side of its base. Install sealant continuous around the Jack Flashing Base.
Step 4 - Cut-out the required vent opening into the DECRA Shingle Panel. Allow a gap around the vent Jack Flashing when cutting the Shingle Panel opening, for positioning and locking the Shingle Panel in place. Use care to not oversize the opening.
Step 5 - Cut-out a 2" wide notch in the nosing of the DECRA Shingle Panel to be placed over the vent pipe, to allow for Shingle Underpan drainage. Center the nosing cut-out with the Jack Flashing.
Step 6 - Place the cut-out DECRA Shingle Panel over the Jack Flashing, and position it into place. Install the Shingle Panel nosing under the Clip Lock of the lower panel, and secure the top of the Shingle Panel to the roof deck.
Step 7 - Install a rubber storm collar over the vent pipe, and lap it over the top of Jack Flashing for 3/4".
Step 8 - Install sealant continuous around the DECRA Shingle Panel vent opening, and finish the installation with DECRA Touch-Up Kit.
Underlayment
Shingle Underpan
Jack Flashing
Fasteners: Min. #8 corrosion resistant screws.
Shingle Panel nose cut-out
2"
1"
℄
Note: Refer to Section Detail at Vent Pipe.
2 S7 VENT FLASHING INSTALLATION
SCALE: 1 1/2" = 1'-0"
DECRA Shingle Hip & Ridge: Fastened through back clip
Owens Corning Ventsure Rigid Roll 7"
Fasteners: Use min. #8 corrosion resistant screws. 6" OC
DECRA Shingle Panel: Stop Panel at vent opening.
Air Flow
Underlayment
Sheathing
Batten
Exist. Shingles
2"
Field verify vent opening
Truss Rafters
3 S7 VENTED RIDGE DETAIL
SCALE: 3" = 1'-0"
DECRA Shingle Hip & Ridge: Fastened through back clip
Rake / Gable Channel
Owens Corning Ventsure Rigid Roll 7"
Fasteners: Use min. #8 corrosion resistant screws. 6" OC
DECRA Shingle Panel: Stop Panel at vent opening.
Air Flow
Underlayment
Sheathing
Batten
Exist. Shingles
2"
Field verify vent opening
Truss Rafters
Fasteners: Use min. #8 corrosion resistant screws.
4 S7 VENTED HIP DETAIL
SCALE: 3" = 1'-0"
REV DESCRIPTION
NORTH CAROLINA PROFESSIONAL SEAL MICHAEL S. MERRICK
BUILDING 8-3846
ROOF RENOVATIONS
CONTRACT NO:
W9132T-06-D-0001 08T0054
FORT BRAGG, NORTH CAROLINA
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DESCRIPTION
SECTIONS & DETAILS
PROJECT 08-4-1260
DATE 4-27-09
SHEET S7 OF 7

Appendix B: Roof Rainwater Runoff to Gutter Calculations for Building 3-2631

PENTA ENGINEERING GROUP, INC.

Calculated By: MBM
Checked By: JBA

Roof Runoff Projection into Gutter

Fort Bragg - Bldg 3-2631

Rainfall, NCPC, 2006 Ed $Rain := 4.5$ in/hour for 1 hour 100-yr return storm

Manning Surface Coefficient $n := 0.015$ Concrete pipe like surface

For 1 second of rain, depth on shingles $d_{rain} := 4.5 \cdot \frac{1}{60} \cdot \frac{1}{60}$ $d_{rain} = 1.25 \times 10^{-3}$ in

Width of Roof $w := 88$ feet

Roof Slope Length $L := 26$ feet

Slope of Roof 3/12 in per in $s := 0.25$ in/in

Volume of Water on a per linear foot basis $a := w \cdot \frac{d_{rain}}{12} \cdot 1$ $a = 9.167 \times 10^{-3}$ ft³

Wetted perimeter of water coming from Roof $p := w + 2 \cdot \frac{d_{rain}}{12}$ $p = 88$ ft²

Hydraulic radius of water flow $r := \frac{a}{p}$ $r = 1.042 \times 10^{-4}$ ft

Velocity of water coming off of roof $V_{rain} := \frac{1.486}{n} \cdot r^{\frac{2}{3}} \cdot s^{\frac{1}{2}}$

$V_{rain} = 0.11$ feet/sec

Travel time from ridge to eave $\Delta t := \frac{L}{V_{rain}}$ $\Delta t = 237.096$ seconds

Depth accumulation of rain from ridge to eave $d_{accum} := \Delta t \cdot d_{rain}$ $d_{accum} = 0.296$ in

Above calculation represent first iteration. Iterate calculations.

PENTA Project No. 08-4-1260 Page 1 of 3 5/13/2010

PENTA ENGINEERING GROUP, INC.

Calculated By: MBM
Checked By: JBA

Iterate volume of water, wetted perimeter, hydraulic radius and water velocity for water depth accumulation until change in time is similar

$\Delta t := 26.6$ seconds

$d := d_{rain} \cdot \Delta t$ $\quad d = 0.033$ in

$a := \frac{d}{12} \cdot 88 \cdot 1$ $\quad a = 0.244$ ft^3

$p := \frac{d}{12} \cdot 2 + 88$ $\quad p = 88.006$ ft^2

$r := \frac{a}{p}$ $\quad r = 2.771 \times 10^{-3}$ ft

$V_t := 1.486 \frac{r^{\frac{2}{3}} \cdot 0.25^{\frac{1}{2}}}{0.015}$ $\quad V_t = 0.977$ ft/sec

$\Delta t_1 := \frac{L}{V_t}$ $\quad \Delta t_1 = 26.609$ seconds

Velocity of water in the horizontal direction with a roof slope of 3/12

$V_{hor} := V_t \cdot \cos\left(\operatorname{atan}\left(\frac{3}{12}\right)\right)$ $\quad V_{hor} = 0.948$ ft/sec

$V_{vert} := V_t \cdot \sin\left(\operatorname{atan}\left(\frac{3}{12}\right)\right)$ $\quad V_{vert} = 0.237$ ft/sec

Time for water to travel 1.25 inches (mid-width of gutter) in the horizontal direction

$t_{hor} := \frac{\frac{1.25}{12}}{V_{hor}}$ $\quad t_{hor} = 0.099$ seconds

Distance water will travel in t_{hor} in the downward direction including gravity acting on water stream.

PENTA
ENGINEERING GROUP, INC.

Calculated By: MBM
Checked By: JBA

$y := \left(-.237 \cdot t_{hor} - 16.1 \cdot t_{hor}{}^{2}\right) \cdot 12$

$y = -2.165$ in

Water will therefore hit bottom of gutter before its outside the limits of the gutter.

Appendix C: Roof Design Drawings for Building H-5834 (SSMR Slope Conversion)

GENERAL NOTES:

1. BASIS OF DESIGN: NORTH CAROLINA STATE BUILDING CODE, 2006 EDITION.
ASCE 7-02 1

A. FLOOR LOADS: NO ALTERATION, EXISTING TWO ELEVATED FLOOR SLABS.

B. ROOF LIVE LOAD: 19 PSF FOR NEW ROOF PANELS.
ROOF FRAMING ADDED TO PROVIDE 5:12 ROOF PITCH.

1
C. GROUND SNOW LOAD: EXISTING ROOF SLOPE INCREASED TO 5:12 PITCH. PLAN DIMENSIONS NOT CHANGED. Pg = 10PSF. BALANCED AND UNBALANCED SNOW LOADS ARE LESS THAN ROOF LIVE LOADS.

D. WIND DESIGN DATA: SPEED: 100 MPH, 3-SECOND GUST.
WIND IMPORTANCE FACTOR: IW = 1.0
ENCLOSED BUILDING GCPI = +/- 0.18

1

ROOF	RAFTERS		ROOF DECKING CLIPS	
ZONE 1 -	+10 PSF	-16 PSF	+11 PSF	-17 PSF
ZONE 2 -	+10 PSF	-22 PSF	+11 PSF	-30 PSF
ZONE 3 -	+10 PSF	-34 PSF	+11 PSF	-44 PSF

MWFRS - NO ALTERATIONS TO STRUCTURAL ELEMENTS. PARAGRAPH 1614.3.

E. SEISMIC DESIGN DATA: NO ALTERATIONS TO STRUCTURAL ELEMENTS, PARAGRAPH 1614.3.

2. SCOPE OF WORK: INSTALL COLD-FORMED METAL ROOF FRAMING AND NEW STANDING SEAM ROOF SYSTEM, WITH GUTTERS, DOWNSPOUTS, AND RELATED SOFFIT AND FACIA FINISHES.

3. MATERIALS: 1

A. ROOF PANELS: 24 GAGE, 50 KSI, GALVALUME STANDING SEAM METAL ROOF PANELS AS MANUFACTURED BY CONSTRUCTION METAL PRODUCTS, STATESVILLE, NORTH CAROLINA.

SERIES 2500 COLORKLAD ULTRA-COOL

COLOR: SAND BEIGE

18-INCH PANEL WIDTH, PENCIL RIBBED PROFILE

WARRANTY: MANUFACTURER SHALL WARRANT THE METAL ROOF AGAINST RUPTURE OR PERFORATION OR FROM STRUCTURALLY FAILING DUE TO NORMAL ATMOSPHERIC CONDITIONS FOR A PERIOD OF TWENTY (20) YEARS. IN ADDITION, MANUFACTURER SHALL PROVIDE A 20 YEAR FINISH WARRANTY AGAINST PEELING AND BLISTERING, CHALK, AND FADE (COLOR CHANGE).

INSTALLER SHALL PROVIDE A WRITTEN WARRANTY FOR TWO (2) YEARS FROM THE DATE OF FINAL COMPLETION AND ACCEPTANCE, GUARANTEEING MATERIALS AND WORKMANSHIP FOR WATERTIGHTNESS, WEATHERTIGHTNESS, AND AGAINST ALL LEAKS. DURING THE INITIAL TWO (2) YEAR PERIOD. THE INSTALLER SHALL ASSURE WEATHERTIGHTNESS AND WATERTIGHTNESS OF THE ROOF WITHOUT ANY COST TO THE BUILDING OWNER.

1
B. FLASHING AND TRIM ACCESSORIES: SHALL BE PROVIDED BY THE PANEL MANUFACTURER AND BE COMPATIBLE WITH AND THE SAME COLOR AS THE PROVIDED ROOF PANELS.

C. COLD-FORMED METAL FRAMING:

MEMBERS SHALL BE 16 GAGE (0.0566 INCH) GALVANIZED STEEL, ASTM A 653/A 653M, GRADE 50, UNLESS NOTED OTHERWISE.

MEMBER SIZES SHALL BE AS INDICATED ON THE DRAWINGS 1

MISCELLANEOUS CONNECTION HARDWARE MANUFACTURED BY THE STEEL NETWORK, INC. OR SIMILAR HARDWARE APPROVED BY THE ENGINEER.

D. FASTENERS:

SCREWS SHALL BE SELF-DRILLING SELF-TAPPING WITH TYPE, SIZE, AND LOCATION AS SHOWN ON THE DRAWINGS.

SCREWS, BOLTS, AND ANCHORS SHALL BE HOT-DIPPED GALVANIZED IN ACCORDANCE WITH ASTM A 123/A 123M OR ASTM A 153/A 153M AS APPROPRIATE.

SCREW PENETRATION THROUGH JOINED MATERIALS SHALL NOT BE LESS THAN THREE EXPOSED THREADS.

MINIMUM SPACINGS AND EDGE DISTANCES FOR SCREWS SHALL BE AS SPECIFIED IN AISI SG02-1.

SCREWS COVERED BY SHEATHING MATERIALS SHALL HAVE LOW PROFILE HEADS.

EXPOSED SCREWS SHALL INCLUDE A COMBINATION STEEL AND NEOPRENE WASHER. SCREW HEAD AND WASHER SHALL BE COLOR MATCHED TO PANEL OR FLASHING.

POP RIVETS SHALL BE STAINLESS STEEL AND COLOR MATCHED TO PANEL OR FLASHING.

E. WELDS: ALL WELDING SHALL BE PERFORMED IN ACCORDANCE WITH AWS D1.3/D1.3M, AS MODIFIED BY AISI SG02-1.

ALL WELDERS, WELDING OPERATIONS, AND WELDING PROCEDURES SHALL BE QUALIFIED ACCORDING TO AWS D1.3/D1.3M.

ALL WELDS SHALL BE CLEANED AND COATED WITH RUST INHIBITIVE GALVANIZING PAINT. DO NOT FIELD WELD MATERIALS LIGHTER THAN 1.2 MM 18 GAGE.

F. CLOSURES AND SEALANTS:

JOINT SEALANTS REQUIRED TO BE APPLIED BETWEEN ROOF PANEL SEAMS SHALL BE NPC SOLAR SEAL 900.

G. EXTERIOR INSULATION AND FINISH SYSTEM (EIFS): STOTHERM CLASSIC NEXT BACKED BY 1/2" DENSGLASS SHEATHING

H. CONCRETE: 3000 PSI MINIMUM 28-DAY COMPRESSIVE STRENGTH, AIR-ENTRAINED. HIGH EARLY STRENGTH ALLOWED 1

I. REINFORCING STEEL: DEFORMED BAR CONFORMING TO ASTM A615, GRADE 60

4. INSTALLATION:

A. FRAMING MEMBERS SHALL BE ERECTED WITHIN FOLLOWING LIMITS:

STUDS: 1/4 INCH IN 8 FEET OUT OF PLUMB, NOT CUMULATIVE; AND

FACE OF FRAMING MEMBERS: 1/4 INCH IN 8 FEET FROM A TRUE PLANE.

B. ROOF PANELS SHALL BE INSTALLED AS FOLLOWS:

PANELS SHALL BE FORMED TO LENGTH. END LAPS WILL NOT BE ALLOWED

FABRICATE FLASHINGS FROM THE SAME MATERIAL AND FINISH AS THE ROOF PANELS

COMPLY WITH MANUFACTURER'S PRODUCT DATA, TECHNICAL BULLETINS, AND INSTALLATION INSTRUCTIONS.

INSTALL PANELS PLUMB, LEVEL, AND STRAIGHT AS INDICATED IN THE PROJECT DRAWINGS.

INSTALL PANEL SYSTEM SO THAT IT IS WITHOUT WAVES, WARPS, BUCKLES, OR DISTORTIONS, AND ALLOW FOR THERMAL MOVEMENTS OF THE PANELS.

USE ONLY SHEARING TYPE TOOLS TO CUT PANELS, AS REQUIRED. ABRASIVE DEVICES SHALL NOT BE USED ON OR NEAR ROOF PANELS.

1
C. FASTENER INSTALLATION:

CONTRACTOR'S QUALITY CONTROL PROGRAM SHALL MONITOR AND ENSURE SELF-TAPPING AND OTHER FASTENERS ARE INSTALLED TO THE PROPER TORQUE, SO AS TO PREVENT UNDER-TIGHTENING OR STRIPPING OUT OF SHEET METAL COMPONENTS.

REV	DESCRIPTION
1	02/19/2009

NORTH CAROLINA PROFESSIONAL SEAL 026098 ENGINEER MICHAEL B. MERRICK
12-17-08

BUILDING H-5834
ROOF RENOVATIONS

CONTRACT NO:
W9132T-06-D-0001 08T0054

FORT BRAGG, NORTH CAROLINA

PENTA ENGINEERING GROUP, INC.
6755 Peachtree Industrial Blvd
Suite 150
Atlanta, Georgia 30360

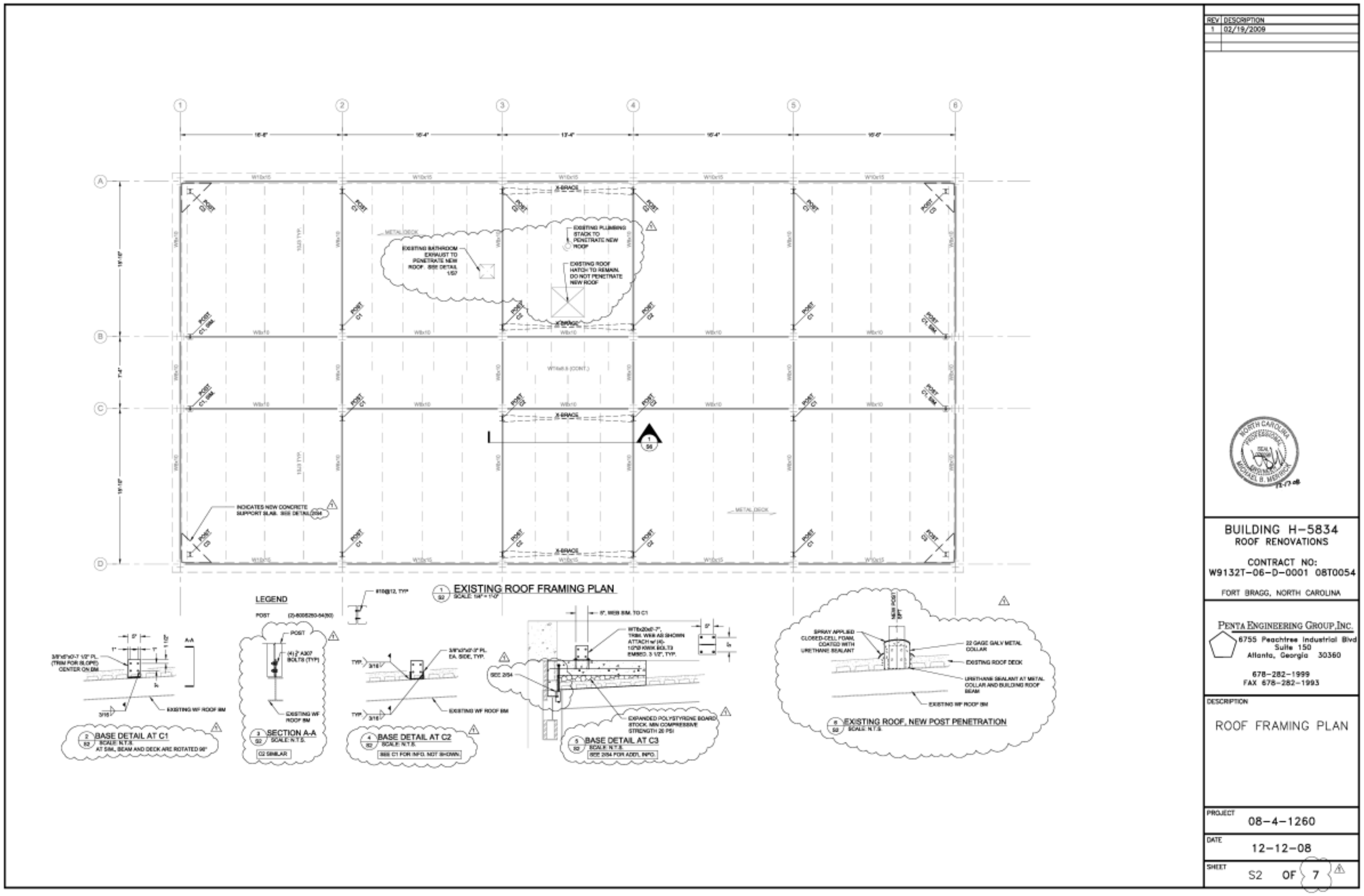
678-282-1999
FAX 678-282-1993

DESCRIPTION
GENERAL NOTES

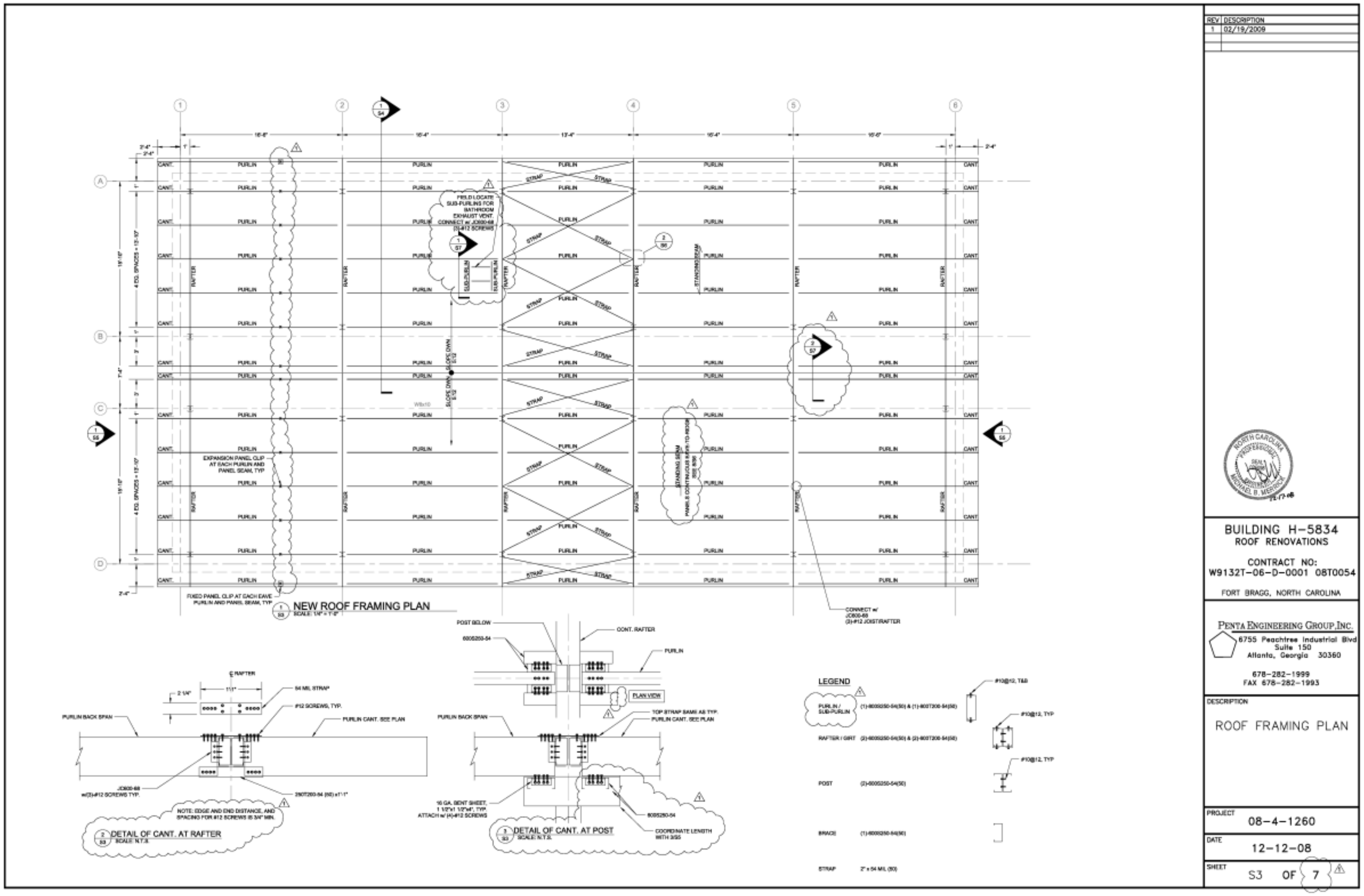
PROJECT
08-4-1260

DATE
12-12-08

SHEET
S1 OF 7 1



REV DESCRIPTION
1 02/19/2009
EXISTING ROOF FRAMING PLAN
LEGEND
BASE DETAIL AT C1
SECTION A-A
BASE DETAIL AT C2
BASE DETAIL AT C3
EXISTING ROOF, NEW POST PENETRATION
BUILDING H-5834
ROOF RENOVATIONS
CONTRACT NO:
W9132T-06-D-0001 08T0054
FORT BRAGG, NORTH CAROLINA
PENTA ENGINEERING GROUP, INC.
6755 Peachtree Industrial Blvd
Suite 150
Atlanta, Georgia 30360
678-282-1999
FAX 678-282-1993
DESCRIPTION
ROOF FRAMING PLAN
PROJECT
08-4-1260
DATE
12-12-08
SHEET
S2 OF 7


REV DESCRIPTION
1 02/19/2009
NEW ROOF FRAMING PLAN
SCALE: 1/4" = 1'-0"
DETAIL OF CANT. AT RAFTER
SCALE: N.T.S.
DETAIL OF CANT. AT POST
SCALE: N.T.S.
LEGEND
BUILDING H-5834
ROOF RENOVATIONS
CONTRACT NO:
W9132T-06-D-0001 08T0054
FORT BRAGG, NORTH CAROLINA
PENTA ENGINEERING GROUP, INC.
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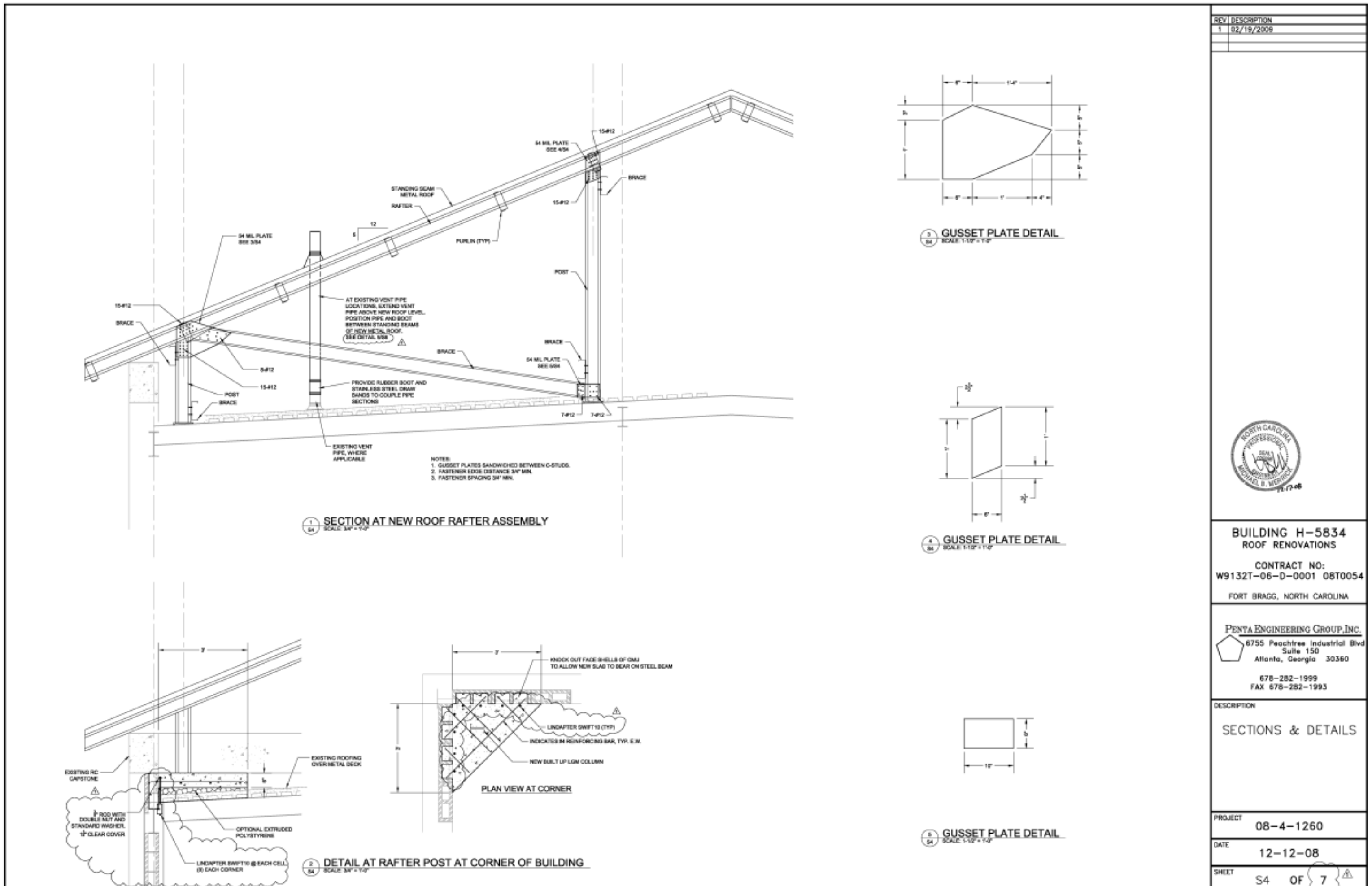
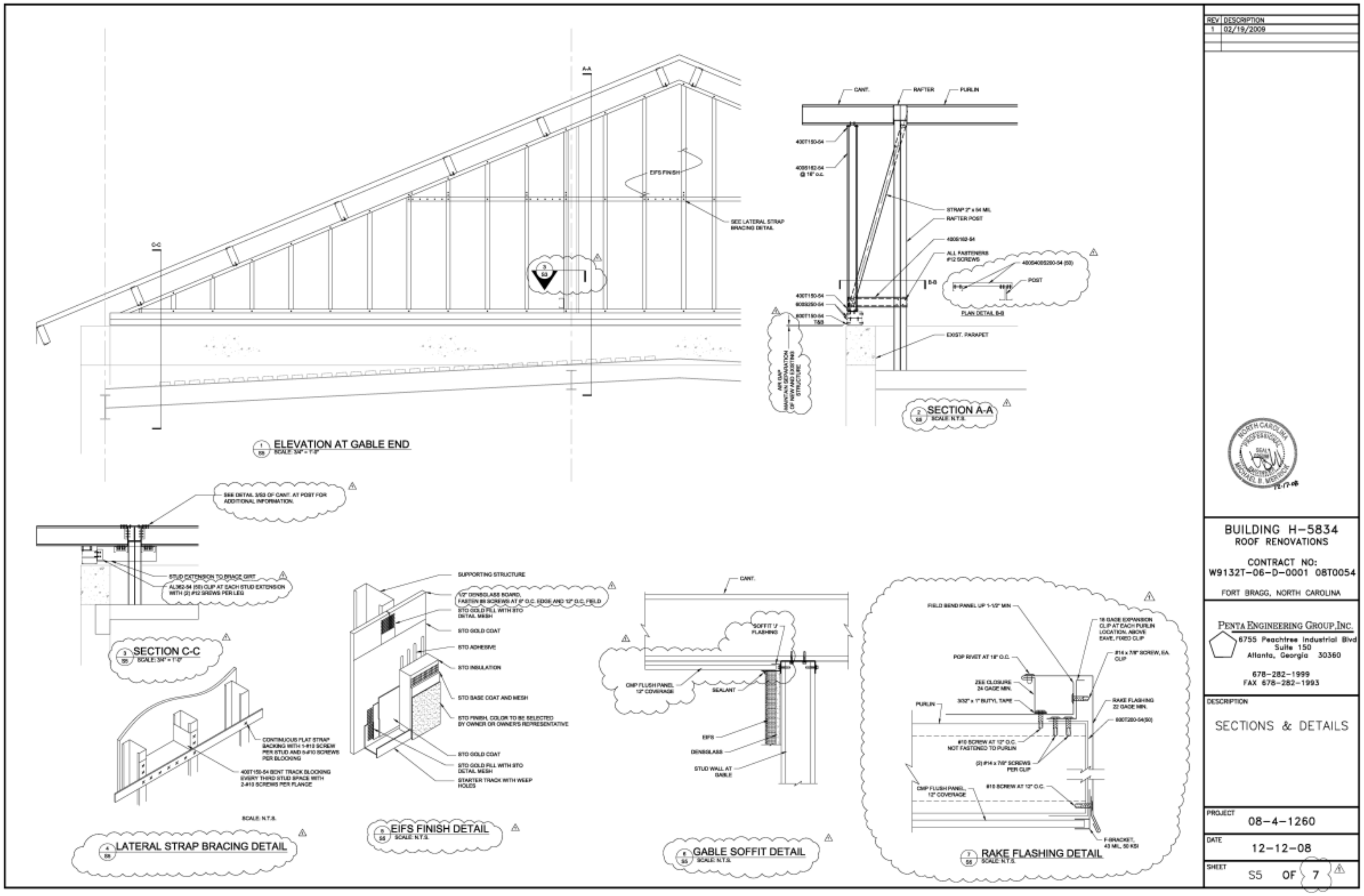
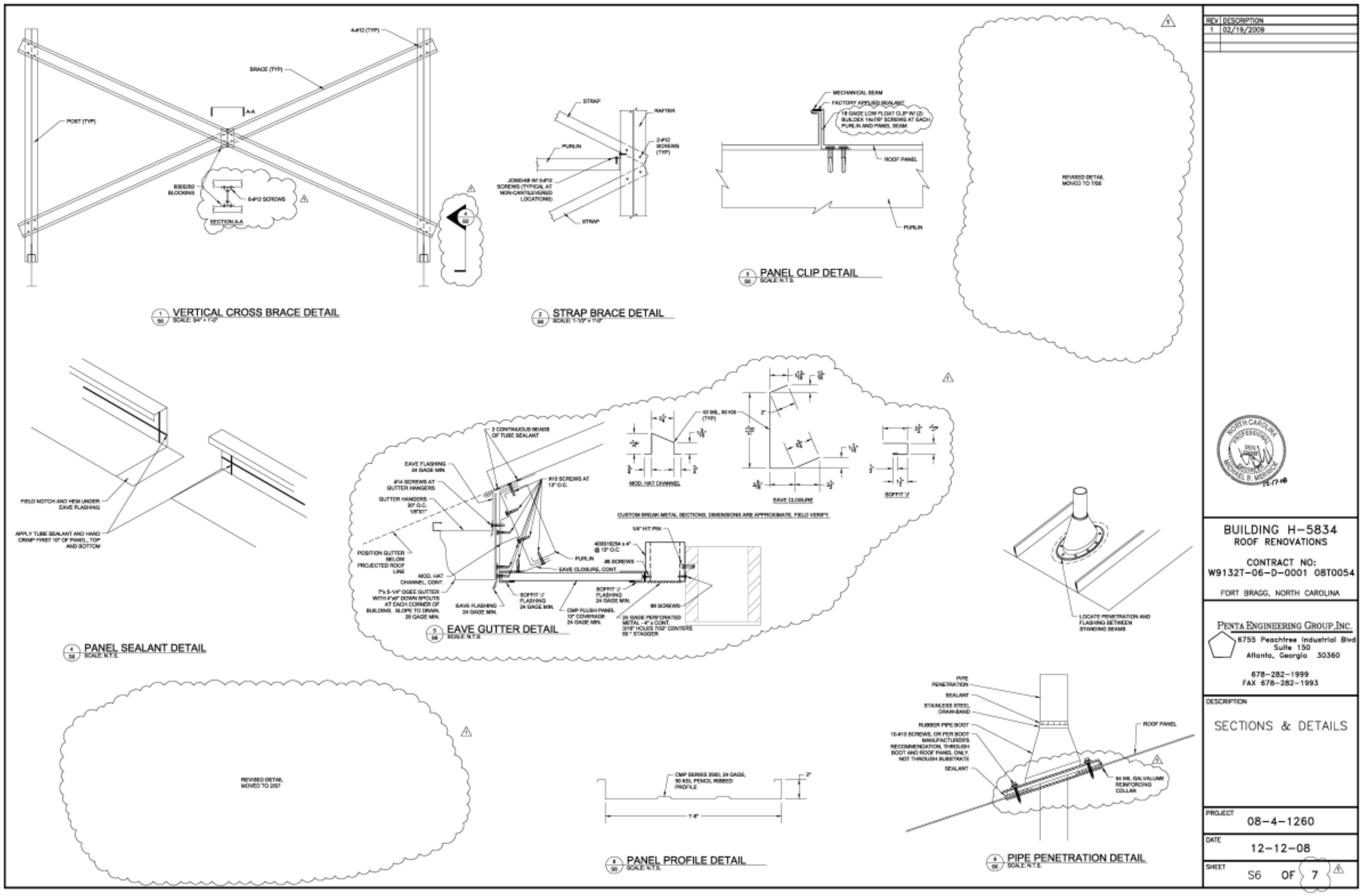
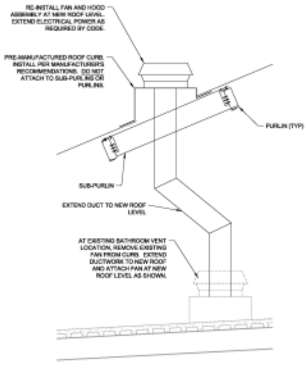
Atlanta, Georgia 30360
678-282-1999
FAX 678-282-1993
DESCRIPTION
ROOF FRAMING PLAN
PROJECT
08-4-1260
DATE
12-12-08
SHEET
S3 OF 7


REV DESCRIPTION
1 02/19/2009
STANDING SEAM METAL ROOF
RAFTER
54 MIL PLATE SEE 3/S4
54 MIL PLATE SEE 4/S4
54 MIL PLATE SEE 5/S4
15-#12
8-#12
7-#12
BRACE
POST
PURLIN (TYP)
AT EXISTING VENT PIPE LOCATIONS, EXTEND VENT PIPE ABOVE NEW ROOF LEVEL. POSITION PIPE AND BOOT BETWEEN STANDING SEAMS OF NEW METAL ROOF.
PROVIDE RUBBER BOOT AND STAINLESS STEEL DRAW BANDS TO COUPLE PIPE SECTIONS
EXISTING VENT PIPE, WHERE APPLICABLE
NOTES:
1. GUSSET PLATES SANDWICHED BETWEEN C-STUDS.
2. FASTENER EDGE DISTANCE 3/4" MIN.
3. FASTENER SPACING 3/4" MIN.
1/S4 SECTION AT NEW ROOF RAFTER ASSEMBLY
SCALE: 3/4" = 1'-0"
3/S4 GUSSET PLATE DETAIL
SCALE: 1-1/2" = 1'-0"
4/S4 GUSSET PLATE DETAIL
SCALE: 1-1/2" = 1'-0"
5/S4 GUSSET PLATE DETAIL
SCALE: 1-1/2" = 1'-0"
EXISTING RC CAPSTONE
EXISTING ROOFING OVER METAL DECK
OPTIONAL EXTRUDED POLYSTYRENE
STANDARD WASHER.
LINDAPTER SWIFT10 @ EACH CELL (8) EACH CORNER
KNOCK OUT FACE SHELLS OF CMU TO ALLOW NEW SLAB TO BEAR ON STEEL BEAM
LINDAPTER SWIFT10 (TYP)
NEW BUILT UP LGM COLUMN
PLAN VIEW AT CORNER
2/S4 DETAIL AT RAFTER POST AT CORNER OF BUILDING
SCALE: 3/4" = 1'-0"
BUILDING H-5834
ROOF RENOVATIONS
CONTRACT NO:
W9132T-06-D-0001 08T0054
FORT BRAGG, NORTH CAROLINA
PENTA ENGINEERING GROUP, INC.
6755 Peachtree Industrial Blvd
Suite 150
Atlanta, Georgia 30360
678-282-1999
FAX 678-282-1993
DESCRIPTION
SECTIONS & DETAILS
PROJECT 08-4-1260
DATE 12-12-08
SHEET S4 OF 7

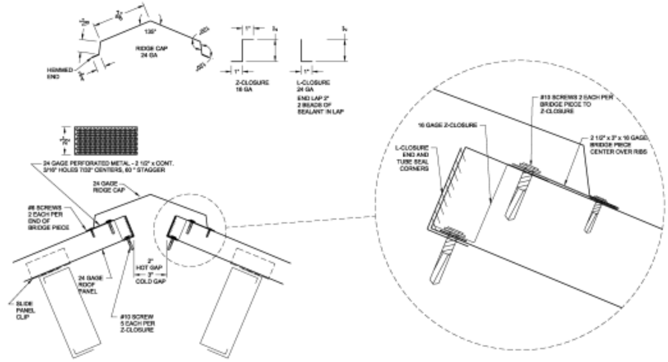

ELEVATION AT GABLE END
SECTION A-A
SECTION C-C
LATERAL STRAP BRACING DETAIL
EIFS FINISH DETAIL
GABLE SOFFIT DETAIL
RAKE FLASHING DETAIL
BUILDING H-5834
ROOF RENOVATIONS
CONTRACT NO:
W9132T-06-D-0001 08T0054
FORT BRAGG, NORTH CAROLINA
PENTA ENGINEERING GROUP, INC.
6755 Peachtree Industrial Blvd
Suite 150
Atlanta, Georgia 30360
678-282-1999
FAX 678-282-1993
SECTIONS & DETAILS
08-4-1260
12-12-08
S5 OF 7



VERTICAL CROSS BRACE DETAIL
STRAP BRACE DETAIL
PANEL CLIP DETAIL
REVISED DETAIL MOVED TO 7/S6
PANEL SEALANT DETAIL
EAVE GUTTER DETAIL
CUSTOM BREAK METAL SECTIONS, DIMENSIONS ARE APPROXIMATE, FIELD VERIFY.
REVISED DETAIL MOVED TO 2/S7
PANEL PROFILE DETAIL
PIPE PENETRATION DETAIL
REV DESCRIPTION
1 02/19/2009
BUILDING H-5834
ROOF RENOVATIONS
CONTRACT NO:
W9132T-06-D-0001 08T0054
FORT BRAGG, NORTH CAROLINA
PENTA ENGINEERING GROUP, INC.
6755 Peachtree Industrial Blvd
Suite 150
Atlanta, Georgia 30360
678-282-1999
FAX 678-282-1993
DESCRIPTION
SECTIONS & DETAILS
PROJECT
08-4-1260
DATE
12-12-08
SHEET
S6 OF 7



1/S7 BATHROOM EXHAUST VENT ASSEMBLY
SCALE: N.T.S.



2/S7 VENTED RIDGE DETAIL
SCALE: N.T.S.

REV	DESCRIPTION
1	02/19/2009

BUILDING H-5834
ROOF RENOVATIONS

CONTRACT NO:
W9132T-06-D-0001 08T0054

FORT BRAGG, NORTH CAROLINA

PENTA ENGINEERING GROUP, INC.
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Atlanta, Georgia 30360

678-282-1999
FAX 678-282-1993

DESCRIPTION
SECTIONS & DETAILS

PROJECT 08-4-1260

DATE 12-12-08

SHEET S7 OF 7

Appendix D: Roof Design Drawings for FRP Panel Systems (Buildings 3-1735, 3-1736, and 3-1737)

GENERAL NOTES:

1. BASIS OF DESIGN: NORTH CAROLINA STATE BUILDING CODE, 2006 EDITION.

   A. FLOOR LOADS: NO ALTERATION, EXISTING CONCRETE SLAB-ON-GRADE.

   B. ROOF LIVE LOAD: 20 PSF FOR ROOF REPLACEMENT PANELS.
      NO ALTERATIONS TO EXISTING BUILDING FRAME.

   C. GROUND SNOW LOAD: NO ALTERATION, EXISTING ROOF SLOPE AND PLAN DIMENSIONS NOT CHANGED.

   D. WIND DESIGN DATA: SPEED: 150 MPH, 3-SECOND GUST.
      WIND IMPORTANCE FACTOR IW = 1.0
      ENCLOSED BUILDING GCPI = +/- 0.18

	ROOF PANELS		ROOF FASTENERS	
ZONE 1 -	+10 PSF	-15 PSF	+10.4 PSF	-16.5 PSF
ZONE 2 -	+10 PSF	-21 PSF	+10.4 PSF	-28.7 PSF
ZONE 3 -	+10 PSF	-33 PSF	+10.4 PSF	-43.4 PSF

      MWFRS - NO ALTERATIONS TO STRUCTURAL ELEMENTS. PARAGRAPH 1614.3.

   E. SEISMIC DESIGN DATA: NO ALTERATIONS TO STRUCTURAL ELEMENTS, PARAGRAPH 1614.3.

2. SCOPE OF WORK: REPLACE EXISTING METAL ROOF PANELS AND ACCESSORIES WITH FIBERGLASS REINFORCED PLASTIC BUILDING PANELS.

3. MATERIALS:

   A. ROOF PANELS: FIBERGLASS REINFORCED PLASTIC ROOF PANELS SHALL BE TUFF SPAN AS MANUFACTURERED BY ENDURO COMPOSITES, FORT WORTH, TEXAS.

      PROFILE SERIES 7.2 X 1.5 SERIES 450.

      GLASS FIBER REINFORCEMENT SHALL BE CONTINUOUS, STRAIGHT, AND BI-DIRECTIONAL.

      GLASS CONTENT SHALL BE A MINIMUM OF 47% BY WEIGHT.

      FLUOROPOLYMER-IMPREGNATED FOR HIGH UV RESISTANCE.
      COLOR SHALL BE WHITE.

   B. FLASHING AND TRIM ACCESSORIES: SHALL BE PROVIDED BY THE PANEL MANUFACTURER AND BE COMPATIBLE WITH THE PROVIDED ROOF PANELS.

   C. FASTENERS:

      ROOF PANEL - TO - PURLIN: STAINLESS STEEL TYP 304, SELF- DRILLING, SFS 338, WITH RUBBER GROMMET WASHERS MIN 0.729 INCHES IN DIAMETER.

      FLASHING AND SIDE LAPS: STAINLESS STEEL GROMMET, 882, WITH FLEXIBLE NEOPRENE WASHERS.

   D. CLOSURES AND SEALANTS:
      I. SEALANT TAPE FOR SIDE AND END LAPS OF OPAQUE PANELS SHALL BE 3/32 INCH THICK, NON-SHRINK/NON-HARDENING BUTYL TAPE.

      II. EPDM CLOSURES SHALL MATCH UNIT PROFILE.

      III.SEALANT FOR TRANSLUCENT PANELS SHALL BE GE SILPRUF.

4. INSTALLATION:

   A. NOTIFY ENGINEER IF EXISTING BUILDING FRAMING TO WHICH ROOF PANEL WILL BE ATTACHED EXBITS CORROSION, SUCH AS RUST, THAT HAS REDUCED THE MEMBER CROSS SECTION.

   B. PREDRILLING NOT REQUIRED IN ROOFING PANELS WHEN USING SFS FASTENERS. FASTENERS SHALL BE NO LESS THAN 1 ½ INCHES FROM THE EDGE OF THE ROOFING PANEL.

   C. NO PILOT HOLES REQUIRED IN SUPPORT WHEN USING SELF-DRILLING SCREWS.

   D. END LAPS SHALL BE 6 INCHES MINIMUM FOR ROOFING PANELS.

   E. ROOFING PANELS SIDE LAPS SHALL BE FASTENED EVERY 18 INCHES MINIMUM.

   F. FLASHING END LAPS SHALL BE 4 INCHES MINIMUM.

REV	DESCRIPTION
1	02/4/2009

NORTH CAROLINA PROFESSIONAL SEAL ENGINEER MICHAEL B. MERRICK

BUILDINGS
3-1735, 1736 & 1737
ROOF RENOVATIONS

CONTRACT NO:
W9132T-06-D-0001 08T0054

FORT BRAGG, NORTH CAROLINA

PENTA ENGINEERING GROUP, INC.
6755 Peachtree Industrial Blvd
Suite 150
Atlanta, Georgia 30360

678-282-1999
FAX 678-282-1993

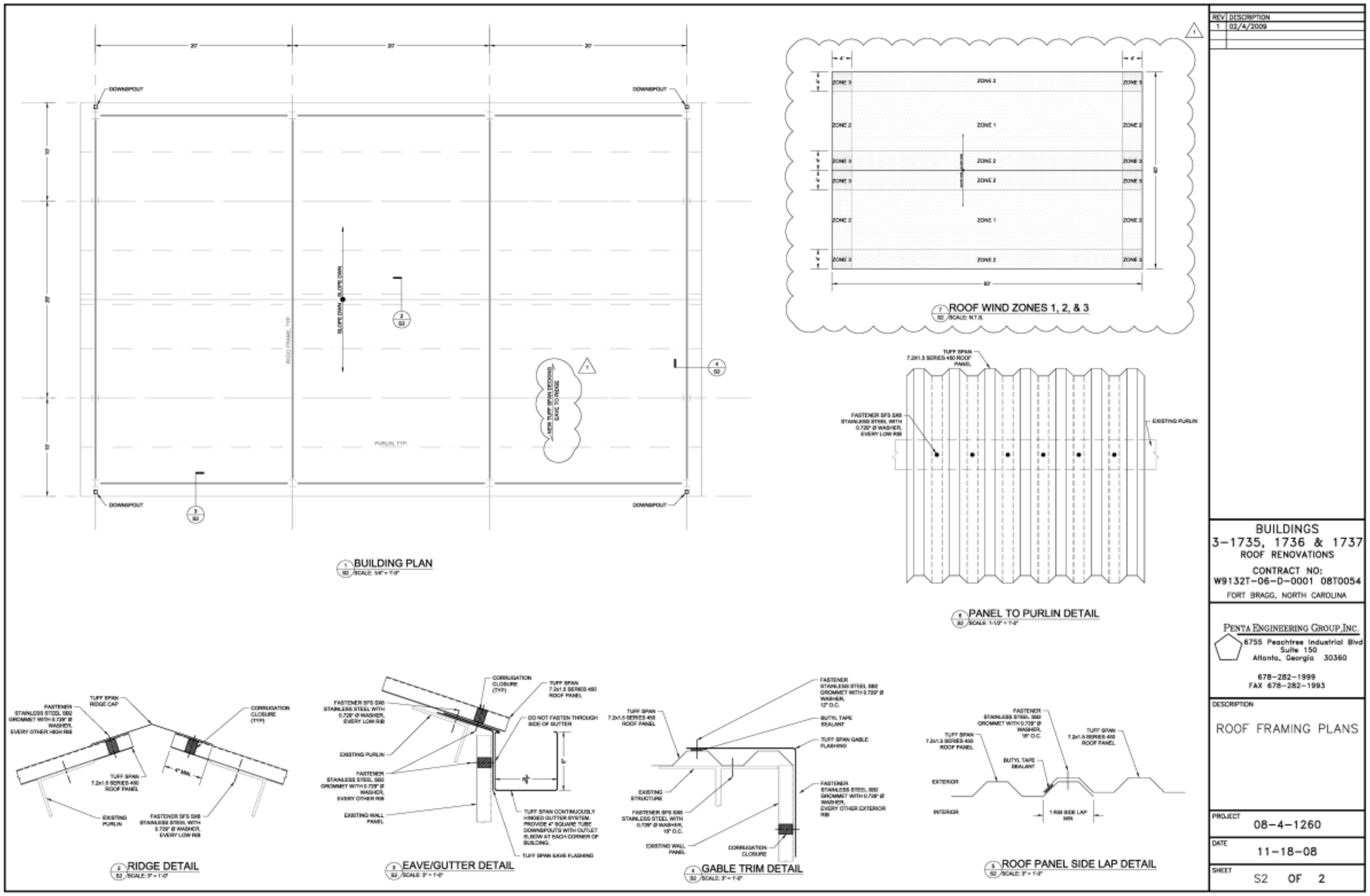
DESCRIPTION

GENERAL NOTES

PROJECT 08-4-1260

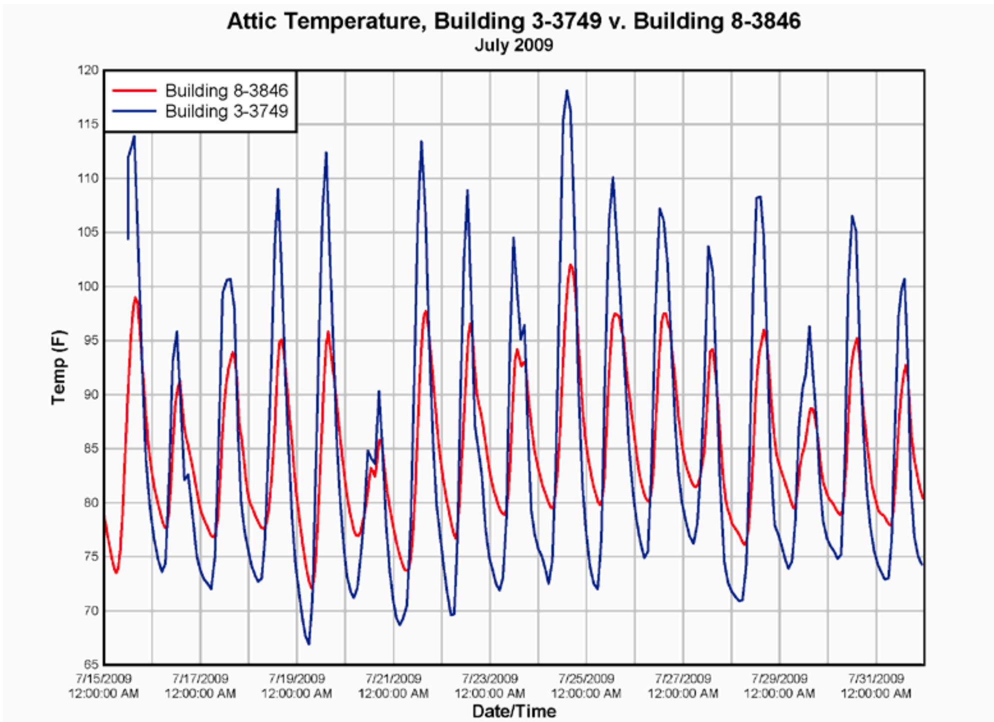
DATE 11-18-08

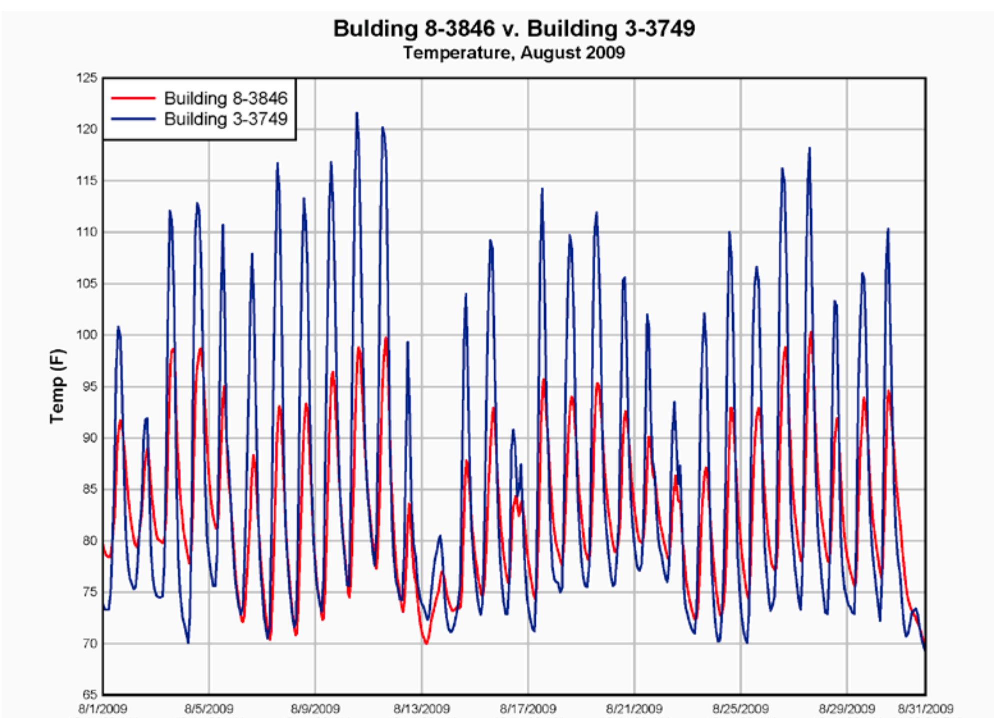
SHEET S1 OF 2

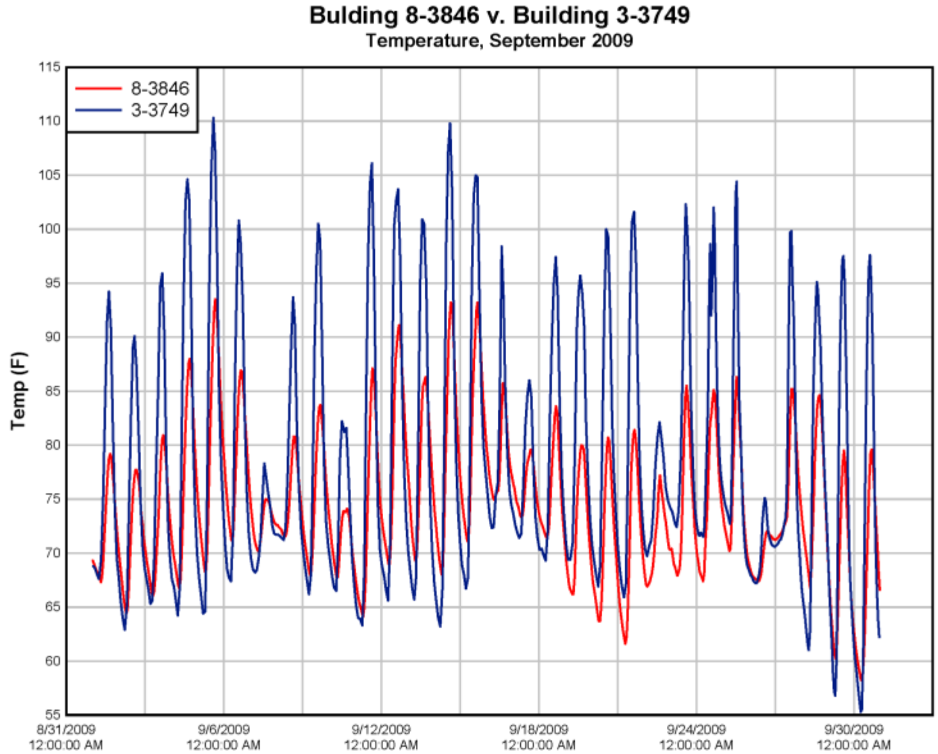


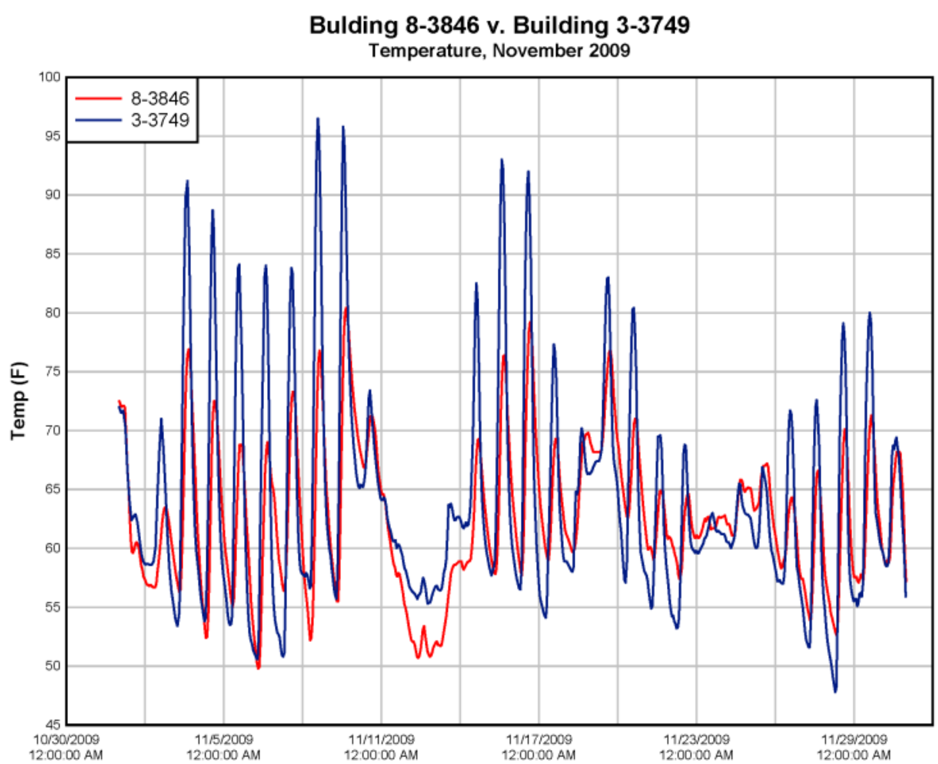
BUILDING PLAN
SCALE: 1/4" = 1'-0"
DOWNSPOUT
SLOPE DOWN
RIGID FRAME, TYP.
PURLIN TYP.
NEW TUFF SPAN SIDING EAVE TO RIDGE
ROOF WIND ZONES 1, 2, & 3
SCALE: N.T.S.
ZONE 1
ZONE 2
ZONE 3
PANEL TO PURLIN DETAIL
SCALE: 1-1/2" = 1'-0"
TUFF SPAN 7.2X1.5 SERIES 450 ROOF PANEL
FASTENER SFS SX6 STAINLESS STEEL WITH 0.729" Ø WASHER, EVERY LOW RIB
EXISTING PURLIN
RIDGE DETAIL
SCALE: 3" = 1'-0"
EAVE/GUTTER DETAIL
SCALE: 3" = 1'-0"
GABLE TRIM DETAIL
SCALE: 3" = 1'-0"
ROOF PANEL SIDE LAP DETAIL
SCALE: 3" = 1'-0"
REV DESCRIPTION
1 02/4/2009
BUILDINGS
3-1735, 1736 & 1737
ROOF RENOVATIONS
CONTRACT NO:
W9132T-06-D-0001 08T0054
FORT BRAGG, NORTH CAROLINA
PENTA ENGINEERING GROUP, INC.
6755 Peachtree Industrial Blvd
Suite 150
Atlanta, Georgia 30360
678-282-1999
FAX 678-282-1993
DESCRIPTION
ROOF FRAMING PLANS
PROJECT
08-4-1260
DATE
11-18-08
SHEET
S2 OF 2

Appendix E: Plots of Attic Sensor Data for Buildings 8-3846 and 8-3749






Bulding 8-3846 v. Building 3-3749
Temperature, September 2009
8-3846
3-3749
Temp (F)
115
110
105
100
95
90
85
80
75
70
65
60
55
8/31/2009 12:00:00 AM
9/6/2009 12:00:00 AM
9/12/2009 12:00:00 AM
9/18/2009 12:00:00 AM
9/24/2009 12:00:00 AM
9/30/2009 12:00:00 AM


Bulding 8-3846 v. Building 3-3749
Temperature, November 2009
8-3846
3-3749
Temp (F)
100
95
90
85
80
75
70
65
60
55
50
45
10/30/2009 12:00:00 AM
11/5/2009 12:00:00 AM
11/11/2009 12:00:00 AM
11/17/2009 12:00:00 AM
11/23/2009 12:00:00 AM
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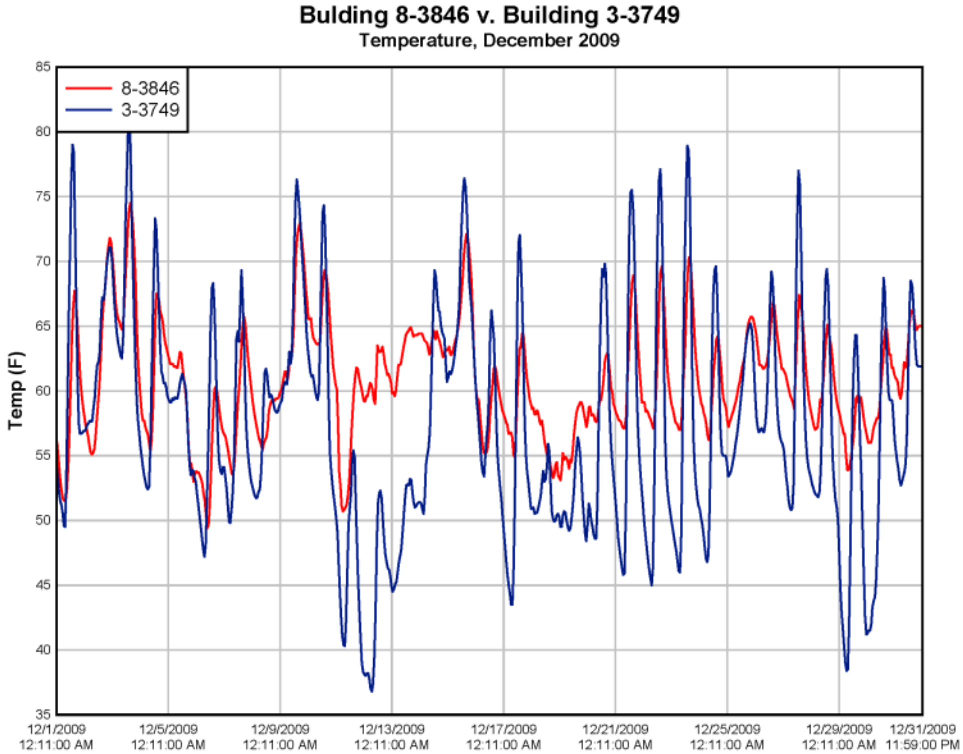
Bulding 8-3846 v. Building 3-3749
Temperature, December 2009
8-3846
3-3749
Temp (F)
85
80
75
70
65
60
55
50
45
40
35
12/1/2009 12:11:00 AM
12/5/2009 12:11:00 AM
12/9/2009 12:11:00 AM
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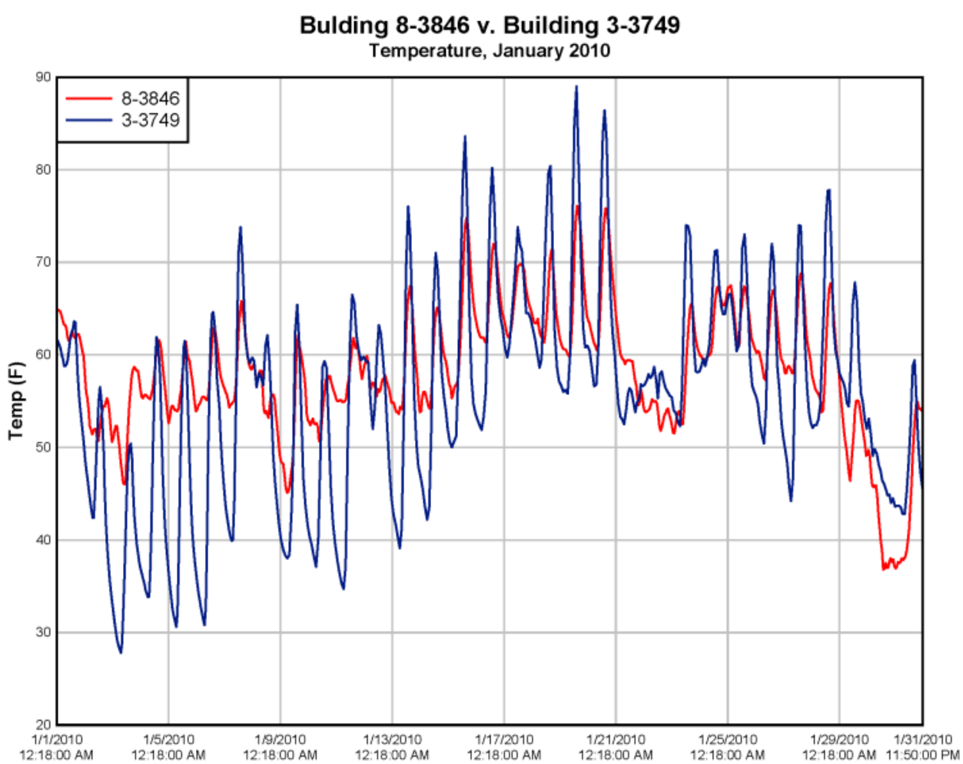
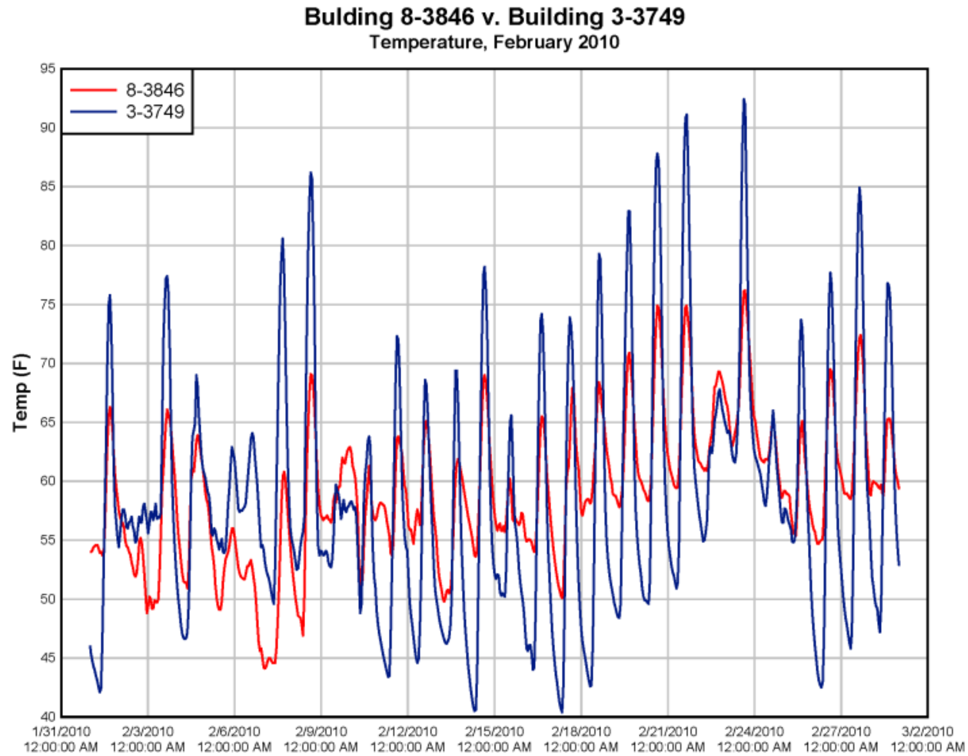
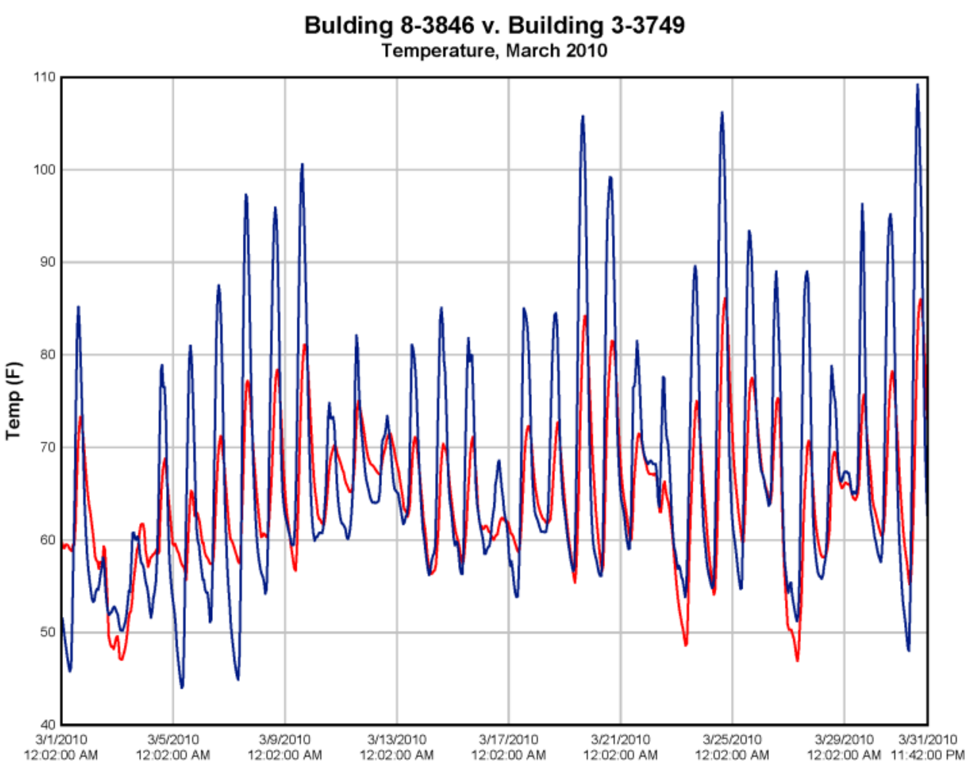
12/29/2009 12:11:00 AM
12/31/2009 11:59:00 PM


Bulding 8-3846 v. Building 3-3749
Temperature, January 2010
8-3846
3-3749
Temp (F)
90
80
70
60
50
40
30
20
1/1/2010 12:18:00 AM
1/5/2010 12:18:00 AM
1/9/2010 12:18:00 AM
1/13/2010 12:18:00 AM
1/17/2010 12:18:00 AM
1/21/2010 12:18:00 AM
1/25/2010 12:18:00 AM
1/29/2010 12:18:00 AM
1/31/2010 11:50:00 PM


Bulding 8-3846 v. Building 3-3749
Temperature, February 2010
8-3846
3-3749
Temp (F)
95
90
85
80
75
70
65
60
55
50
45
40
1/31/2010 12:00:00 AM
2/3/2010 12:00:00 AM
2/6/2010 12:00:00 AM
2/9/2010 12:00:00 AM
2/12/2010 12:00:00 AM
2/15/2010 12:00:00 AM
2/18/2010 12:00:00 AM
2/21/2010 12:00:00 AM
2/24/2010 12:00:00 AM
2/27/2010 12:00:00 AM
3/2/2010 12:00:00 AM


Bulding 8-3846 v. Building 3-3749
Temperature, March 2010
Temp (F)
110
100
90
80
70
60
50
40
3/1/2010 12:02:00 AM
3/5/2010 12:02:00 AM
3/9/2010 12:02:00 AM
3/13/2010 12:02:00 AM
3/17/2010 12:02:00 AM
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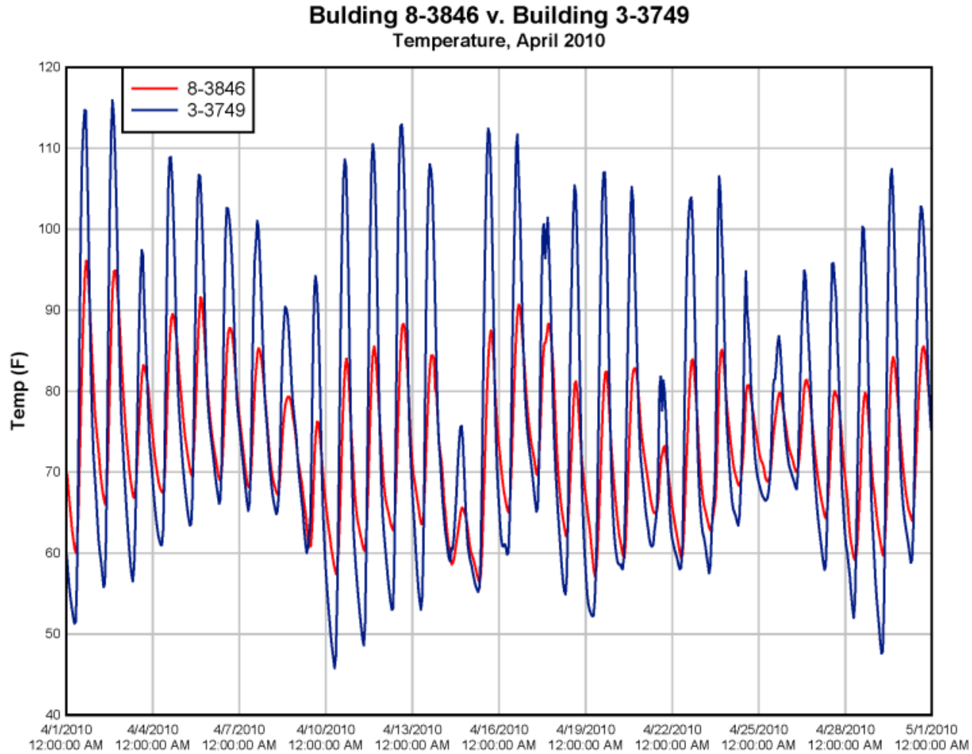
3/29/2010 12:02:00 AM
3/31/2010 11:42:00 PM


Bulding 8-3846 v. Building 3-3749
Temperature, April 2010
8-3846
3-3749
Temp (F)
120
110
100
90
80
70
60
50
40
4/1/2010 12:00:00 AM
4/4/2010 12:00:00 AM
4/7/2010 12:00:00 AM
4/10/2010 12:00:00 AM
4/13/2010 12:00:00 AM
4/16/2010 12:00:00 AM
4/19/2010 12:00:00 AM
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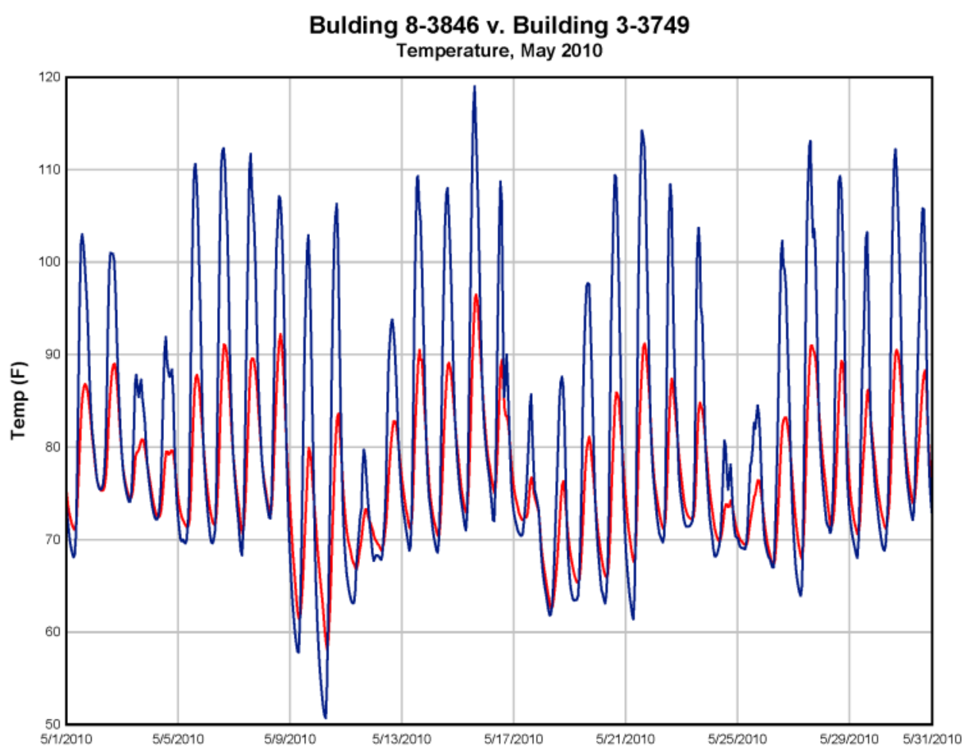
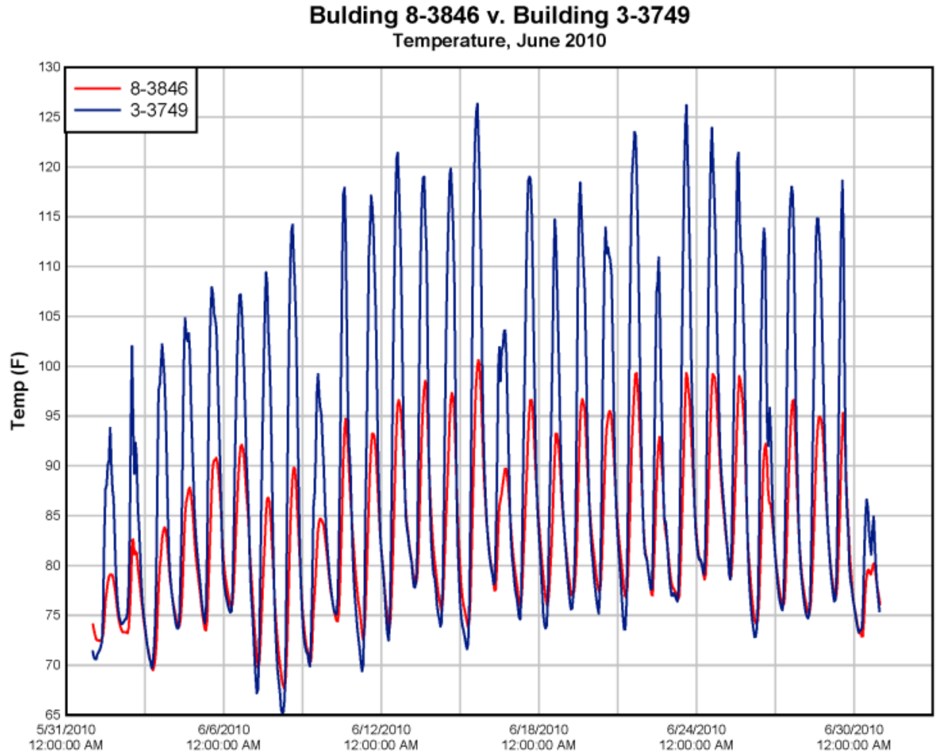
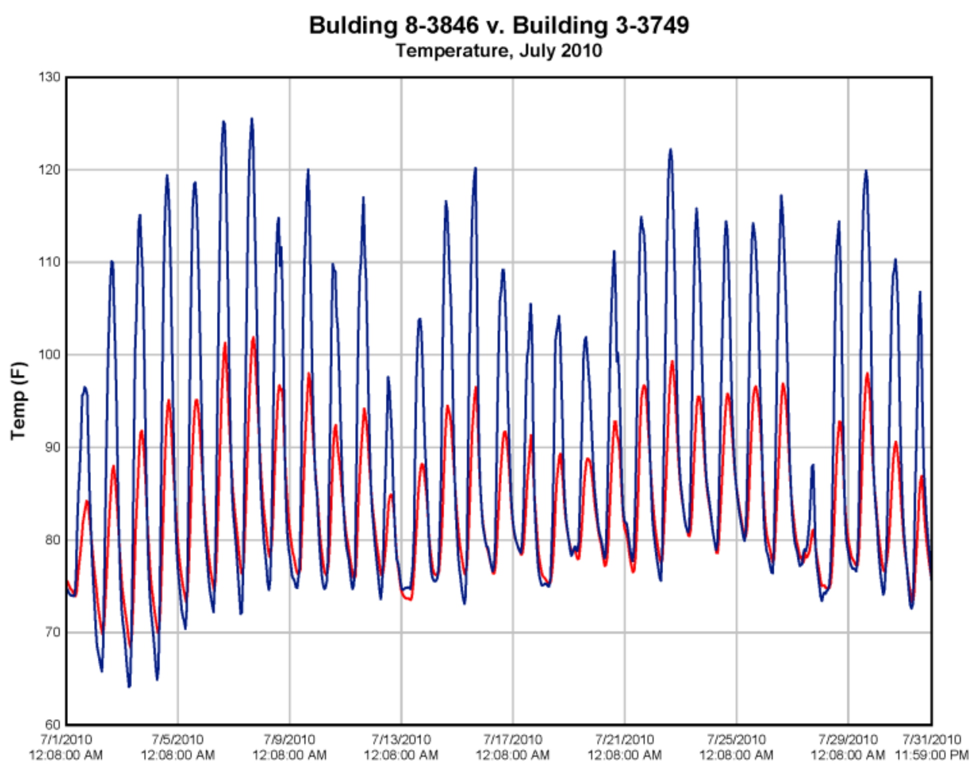
4/25/2010 12:00:00 AM
4/28/2010 12:00:00 AM
5/1/2010 12:00:00 AM


Bulding 8-3846 v. Building 3-3749
Temperature, May 2010
Temp (F)
120
110
100
90
80
70
60
50
5/1/2010 12:07:00 AM
5/5/2010 12:07:00 AM
5/9/2010 12:07:00 AM
5/13/2010 12:07:00 AM
5/17/2010 12:07:00 AM
5/21/2010 12:07:00 AM
5/25/2010 12:07:00 AM
5/29/2010 12:07:00 AM
5/31/2010 11:11:00 PM


Building 8-3846 v. Building 3-3749
Temperature, June 2010
8-3846
3-3749
Temp (F)
130
125
120
115
110
105
100
95
90
85
80
75
70
65
5/31/2010 12:00:00 AM
6/6/2010 12:00:00 AM
6/12/2010 12:00:00 AM
6/18/2010 12:00:00 AM
6/24/2010 12:00:00 AM
6/30/2010 12:00:00 AM


Building 8-3846 v. Building 3-3749
Temperature, July 2010
Temp (F)
130
120
110
100
90
80
70
60
7/1/2010 12:08:00 AM
7/5/2010 12:08:00 AM
7/9/2010 12:08:00 AM
7/13/2010 12:08:00 AM
7/17/2010 12:08:00 AM
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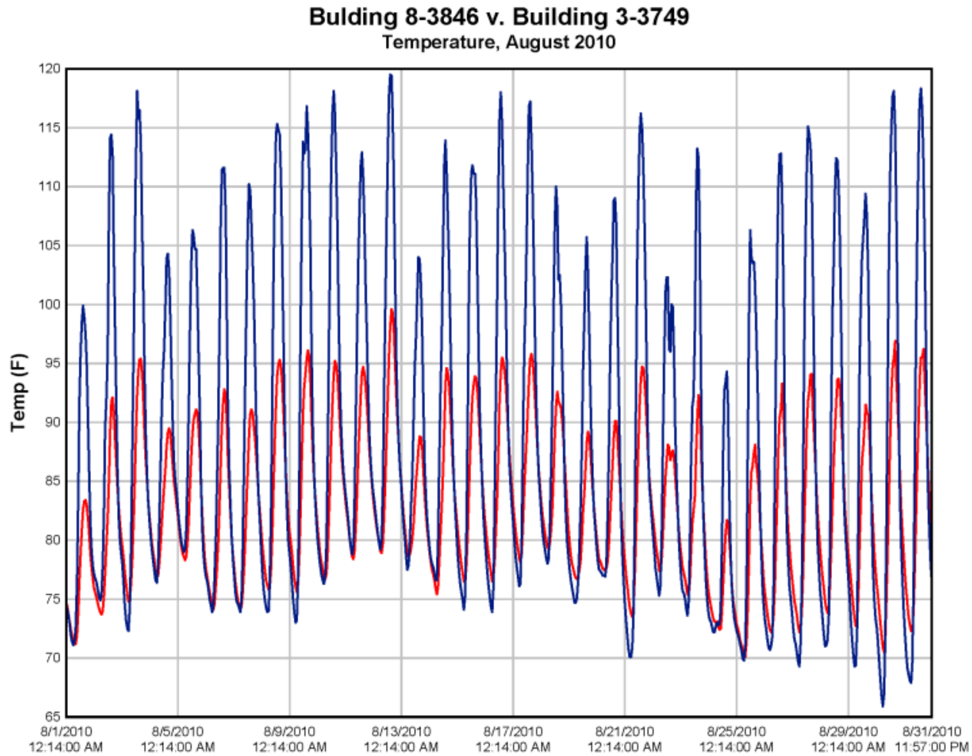
7/25/2010 12:08:00 AM
7/29/2010 12:08:00 AM
7/31/2010 11:59:00 PM


Bulding 8-3846 v. Building 3-3749
Temperature, August 2010
Temp (F)
120
115
110
105
100
95
90
85
80
75
70
65
8/1/2010 12:14:00 AM
8/5/2010 12:14:00 AM
8/9/2010 12:14:00 AM
8/13/2010 12:14:00 AM
8/17/2010 12:14:00 AM
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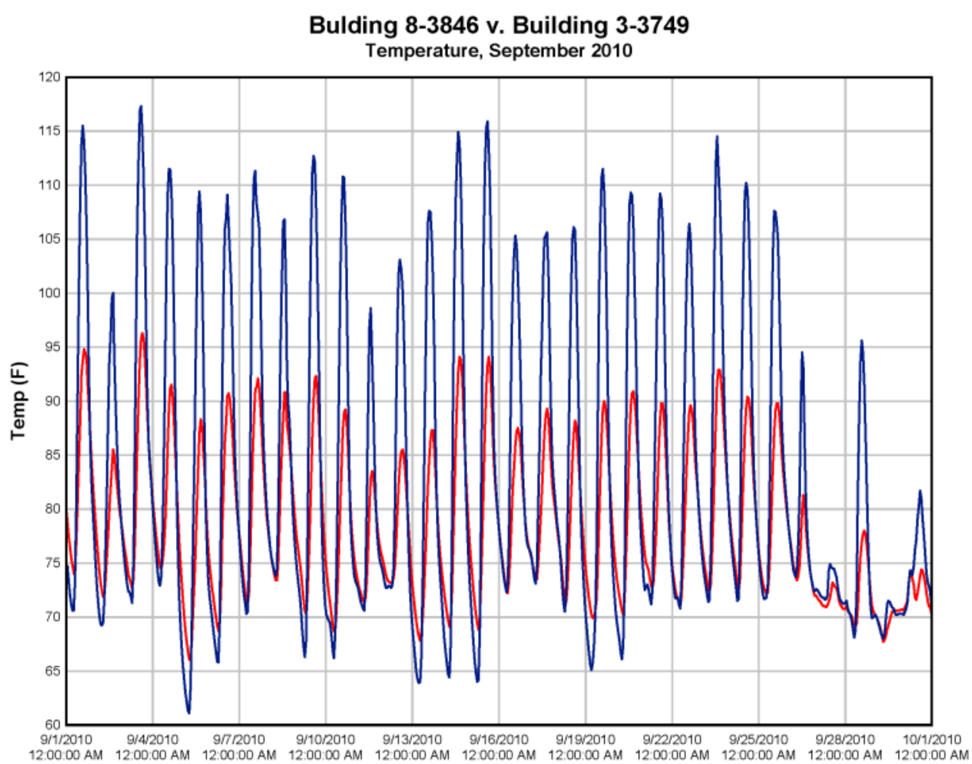
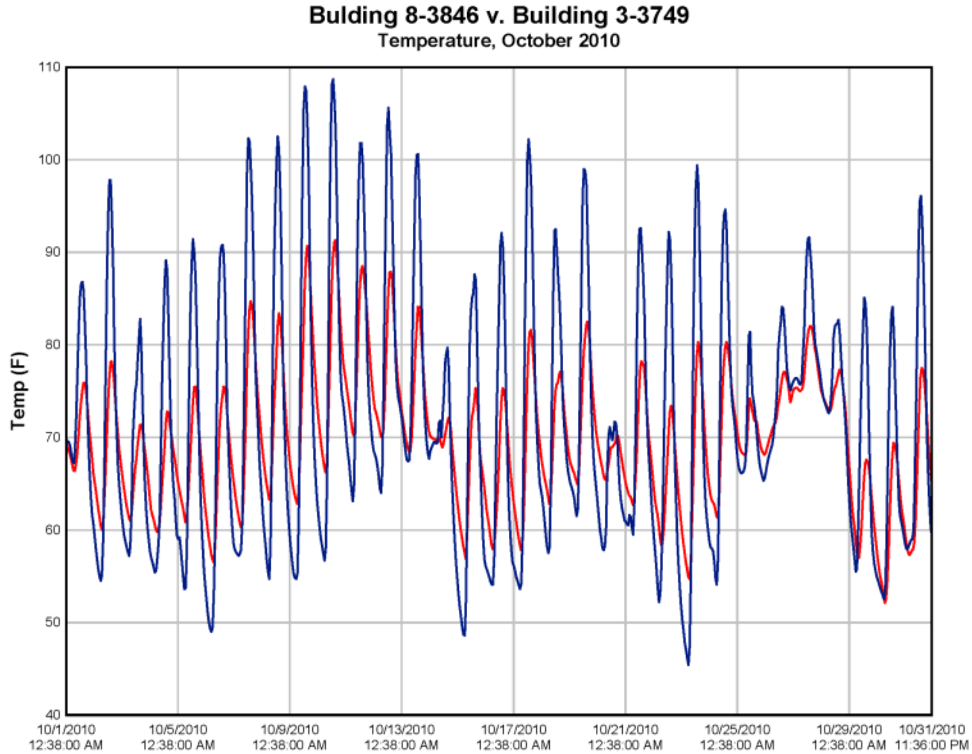
8/25/2010 12:14:00 AM
8/29/2010 12:14:00 AM
8/31/2010 11:57:00 PM


Bulding 8-3846 v. Building 3-3749
Temperature, September 2010
Temp (F)
120
115
110
105
100
95
90
85
80
75
70
65
60
9/1/2010 12:00:00 AM
9/4/2010 12:00:00 AM
9/7/2010 12:00:00 AM
9/10/2010 12:00:00 AM
9/13/2010 12:00:00 AM
9/16/2010 12:00:00 AM
9/19/2010 12:00:00 AM
9/22/2010 12:00:00 AM
9/25/2010 12:00:00 AM
9/28/2010 12:00:00 AM
10/1/2010 12:00:00 AM


Bulding 8-3846 v. Building 3-3749
Temperature, October 2010
Temp (F)
110
100
90
80
70
60
50
40
10/1/2010 12:38:00 AM
10/5/2010 12:38:00 AM
10/9/2010 12:38:00 AM
10/13/2010 12:38:00 AM
10/17/2010 12:38:00 AM
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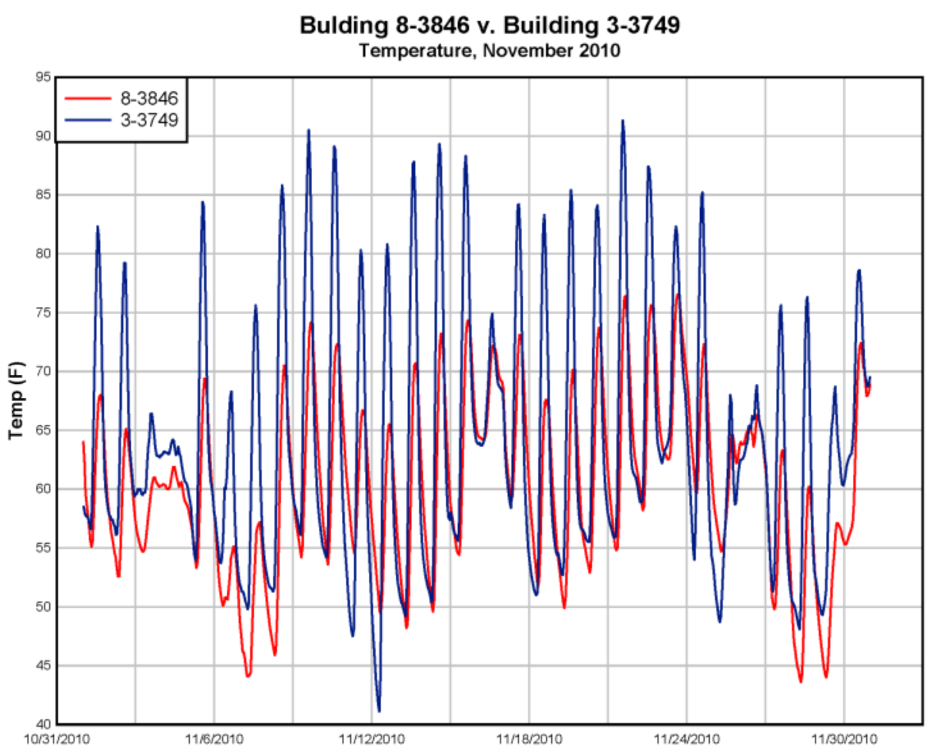
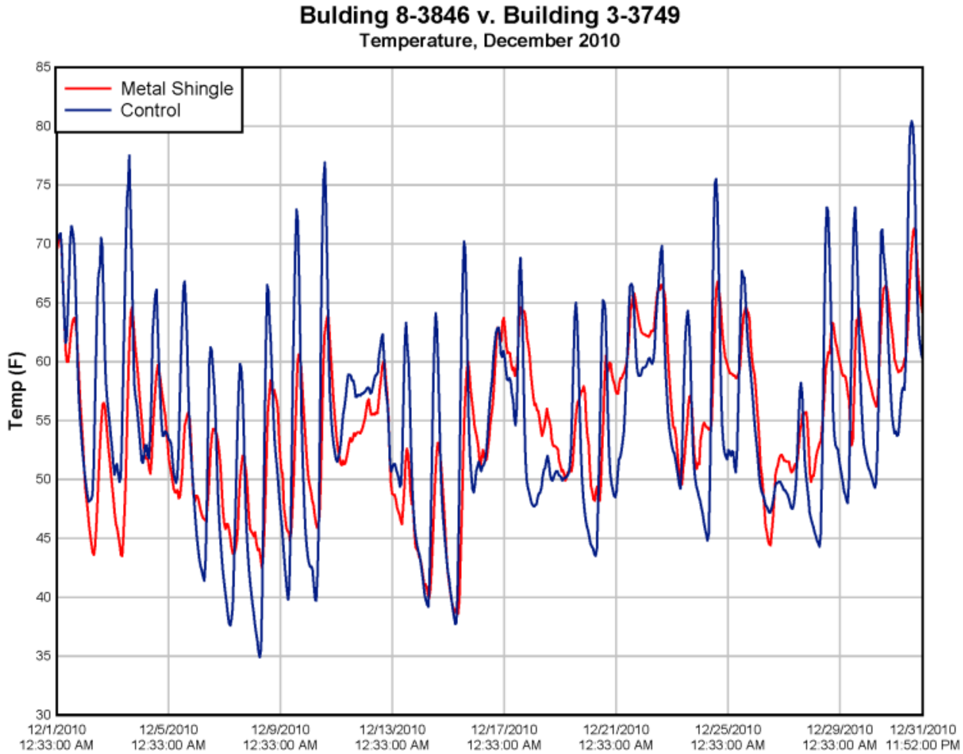
10/31/2010 11:36:00 PM


Bulding 8-3846 v. Building 3-3749
Temperature, November 2010
8-3846
3-3749
Temp (F)
95
90
85
80
75
70
65
60
55
50
45
40
10/31/2010 12:00:00 AM
11/6/2010 12:00:00 AM
11/12/2010 12:00:00 AM
11/18/2010 12:00:00 AM
11/24/2010 12:00:00 AM
11/30/2010 12:00:00 AM


Bulding 8-3846 v. Building 3-3749
Temperature, December 2010
Metal Shingle
Control
Temp (F)
85
80
75
70
65
60
55
50
45
40
35
30
12/1/2010 12:33:00 AM
12/5/2010 12:33:00 AM
12/9/2010 12:33:00 AM
12/13/2010 12:33:00 AM
12/17/2010 12:33:00 AM
12/21/2010 12:33:00 AM
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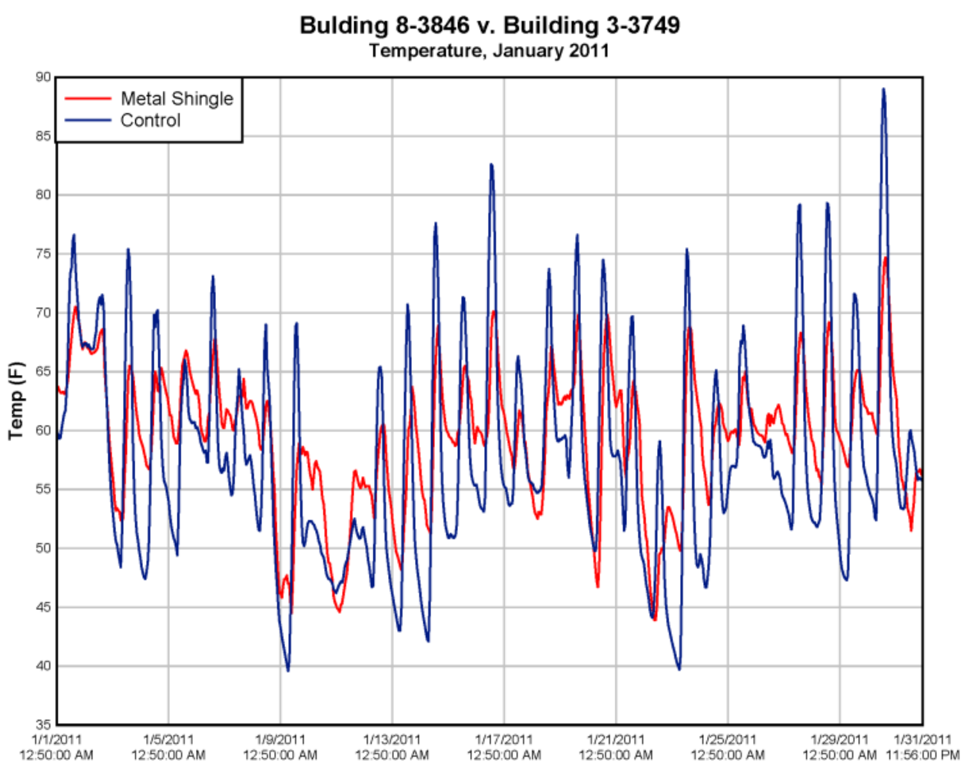
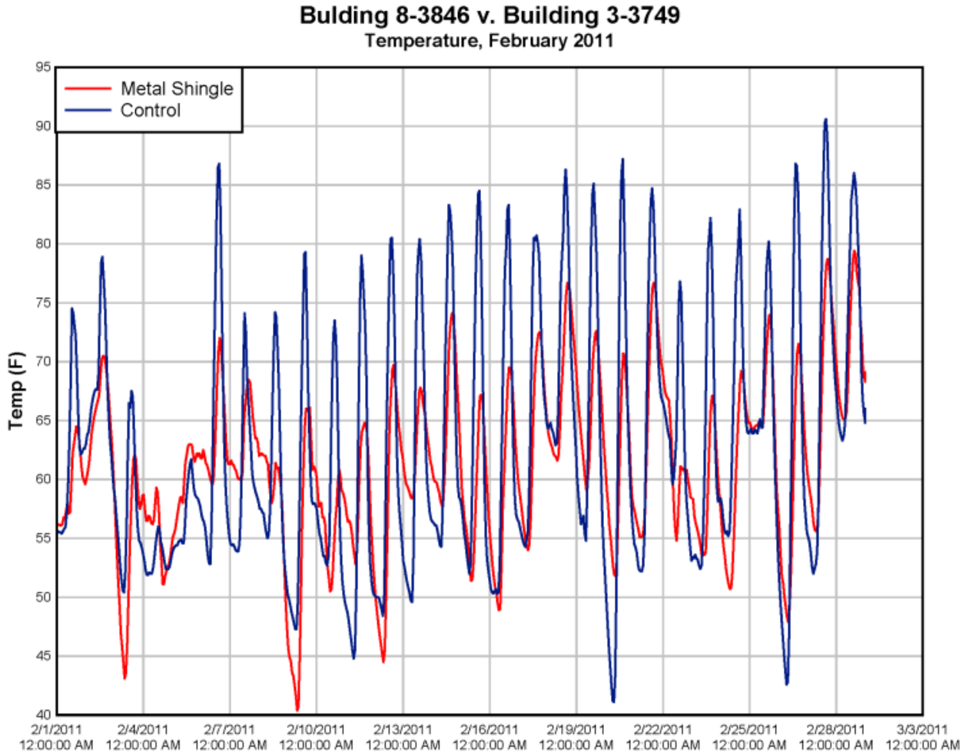
12/31/2010 11:52:00 PM


Bulding 8-3846 v. Building 3-3749
Temperature, January 2011
Metal Shingle
Control
Temp (F)
90
85
80
75
70
65
60
55
50
45
40
35
1/1/2011 12:50:00 AM
1/5/2011 12:50:00 AM
1/9/2011 12:50:00 AM
1/13/2011 12:50:00 AM
1/17/2011 12:50:00 AM
1/21/2011 12:50:00 AM
1/25/2011 12:50:00 AM
1/29/2011 12:50:00 AM
1/31/2011 11:56:00 PM


Bulding 8-3846 v. Building 3-3749
Temperature, February 2011
Metal Shingle
Control
Temp (F)
95
90
85
80
75
70
65
60
55
50
45
40
2/1/2011 12:00:00 AM
2/4/2011 12:00:00 AM
2/7/2011 12:00:00 AM
2/10/2011 12:00:00 AM
2/13/2011 12:00:00 AM
2/16/2011 12:00:00 AM
2/19/2011 12:00:00 AM
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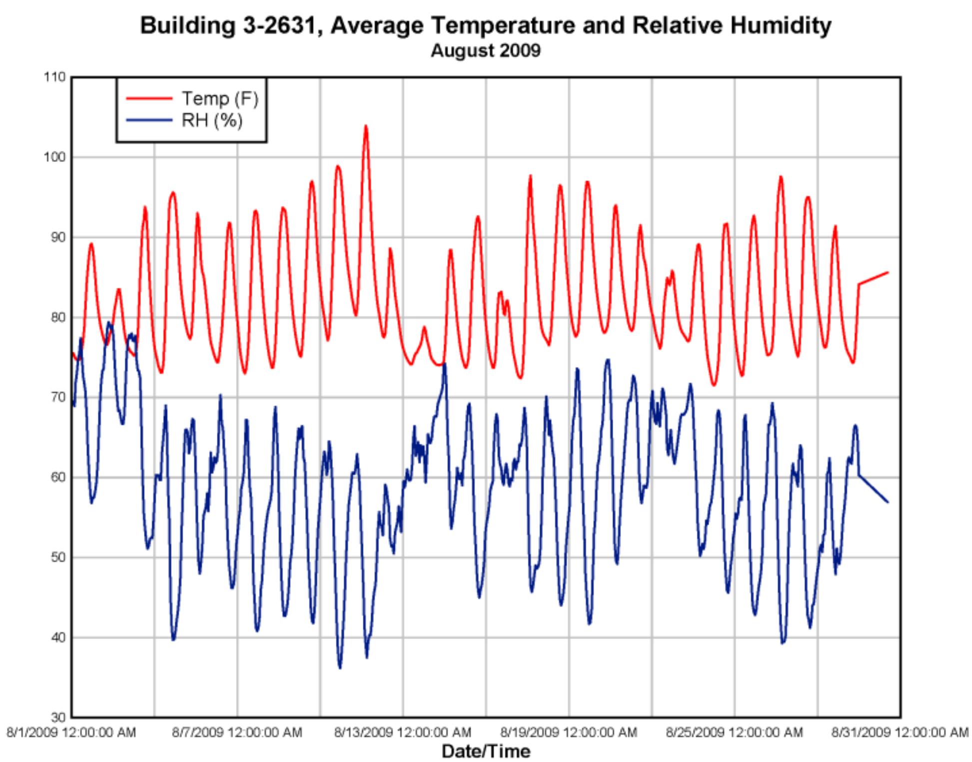
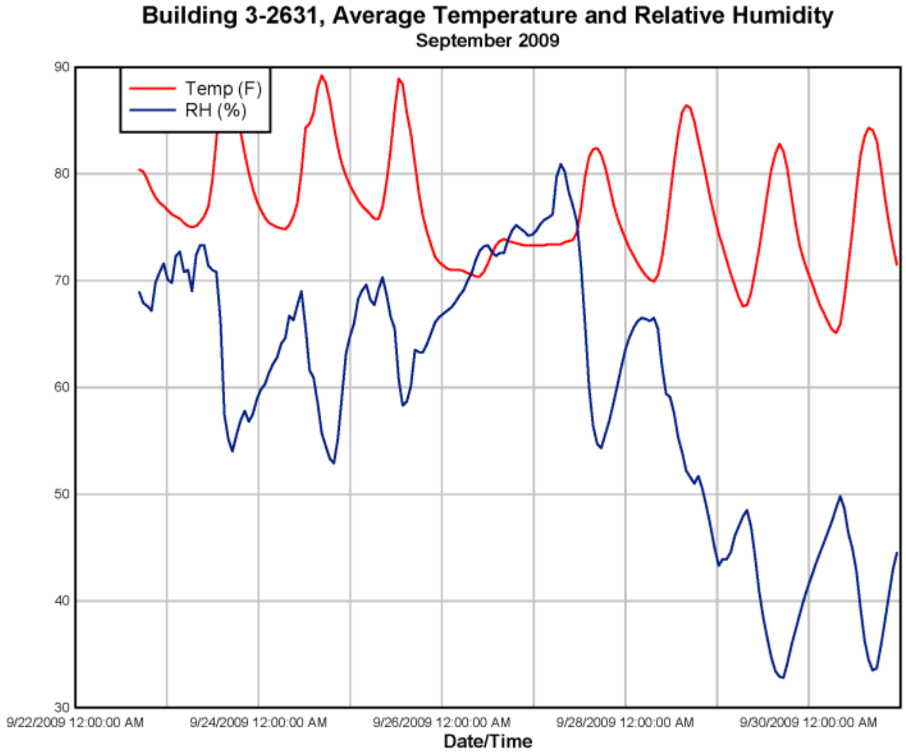
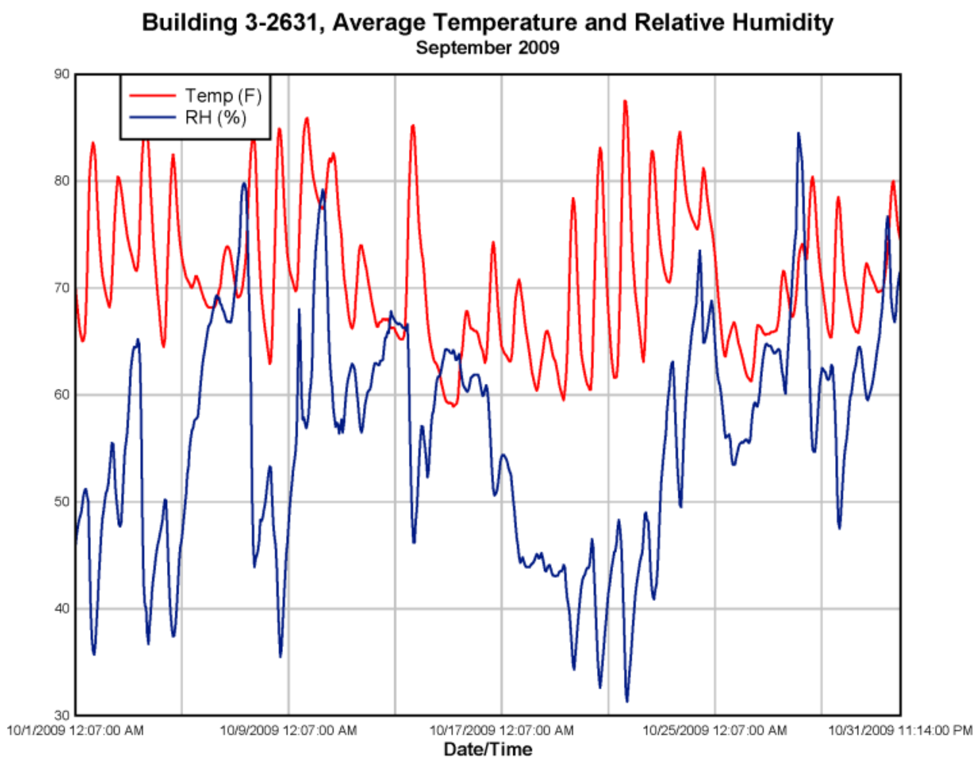
3/3/2011 12:00:00 AM

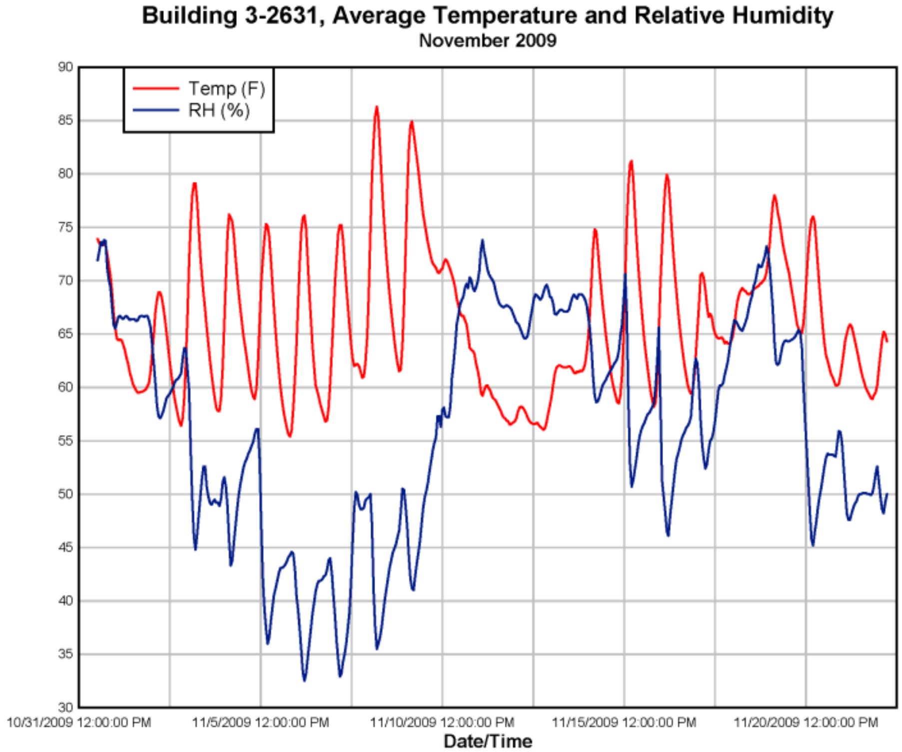

Building 3-2631, Average Temperature and Relative Humidity
August 2009
Temp (F)
RH (%)
110
100
90
80
70
60
50
40
30
8/1/2009 12:00:00 AM
8/7/2009 12:00:00 AM
8/13/2009 12:00:00 AM
8/19/2009 12:00:00 AM
8/25/2009 12:00:00 AM
8/31/2009 12:00:00 AM
Date/Time

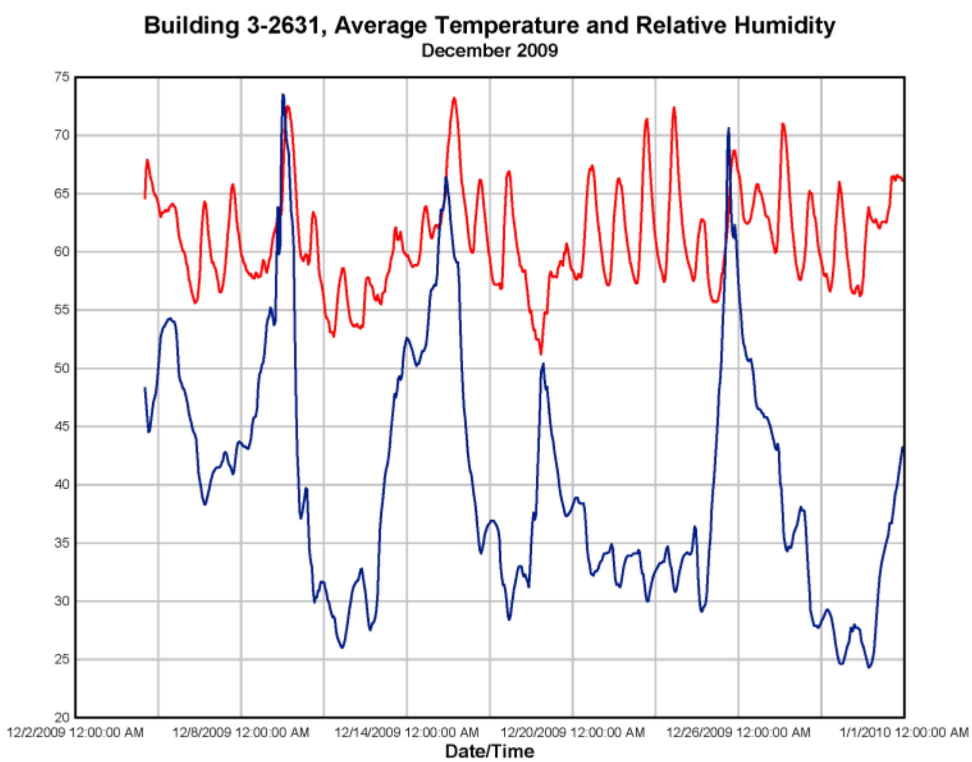


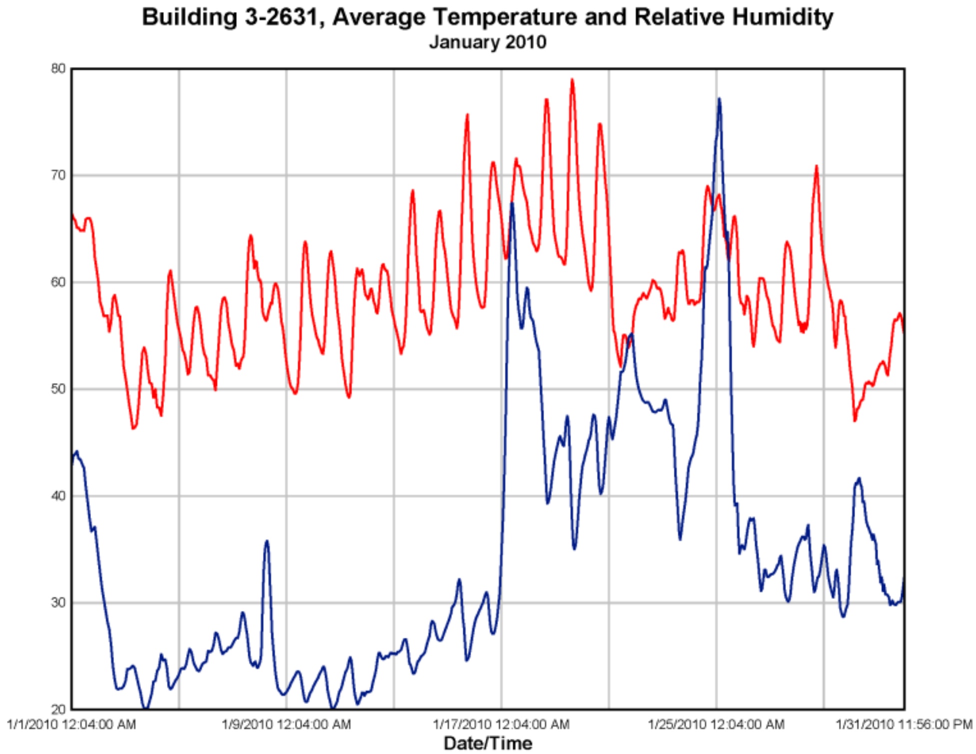
Building 3-2631, Average Temperature and Relative Humidity
September 2009
Temp (F)
RH (%)
90
80
70
60
50
40
30
9/22/2009 12:00:00 AM
9/24/2009 12:00:00 AM
9/26/2009 12:00:00 AM
9/28/2009 12:00:00 AM
9/30/2009 12:00:00 AM
Date/Time

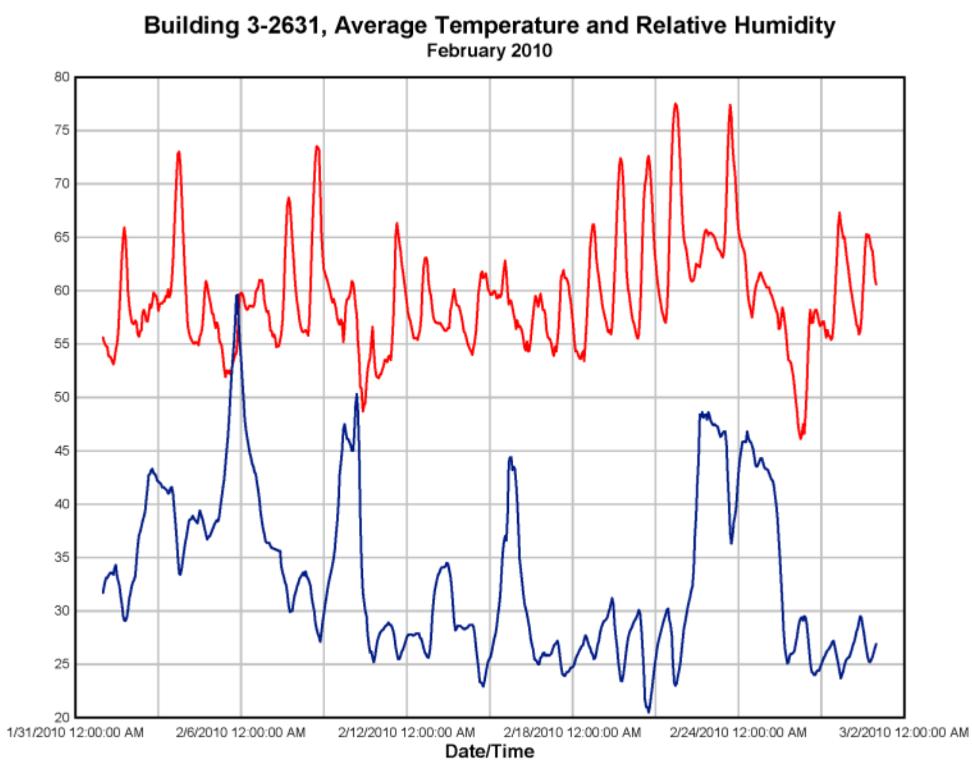


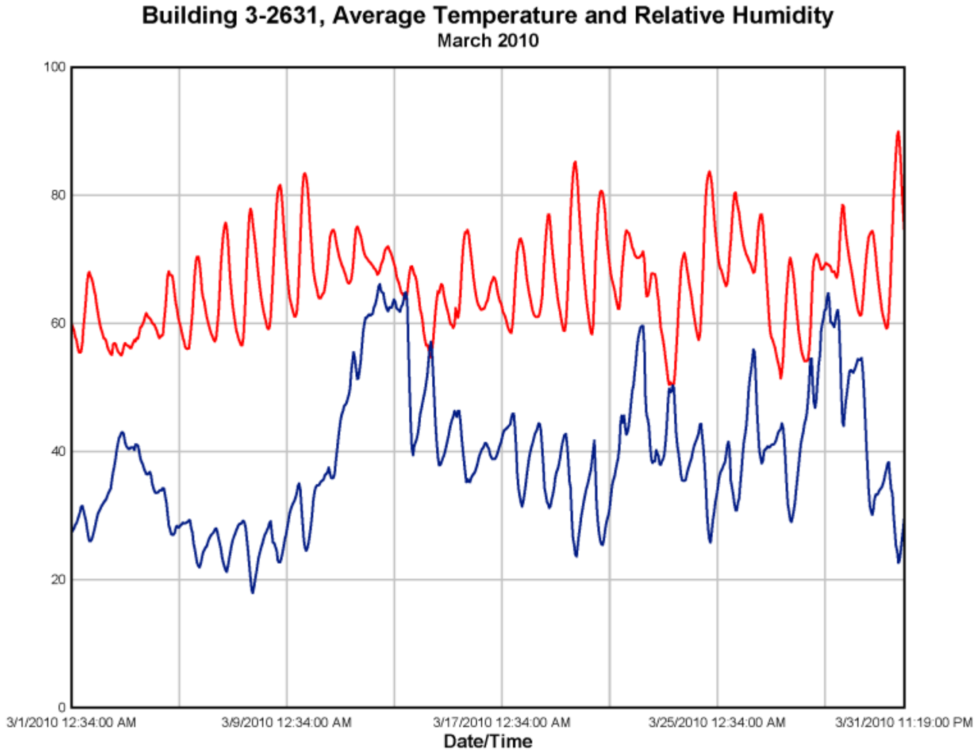
Building 3-2631, Average Temperature and Relative Humidity
September 2009
Temp (F)
RH (%)
90
80
70
60
50
40
30
10/1/2009 12:07:00 AM
10/9/2009 12:07:00 AM
10/17/2009 12:07:00 AM
10/25/2009 12:07:00 AM
10/31/2009 11:14:00 PM
Date/Time

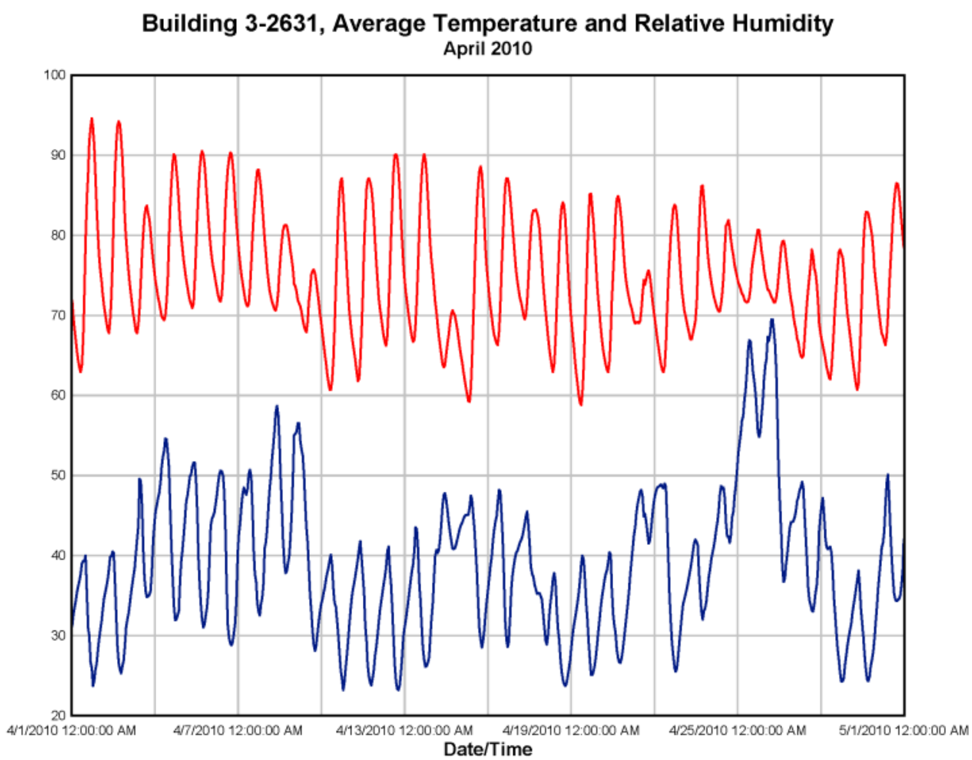

Building 3-2631, Average Temperature and Relative Humidity
November 2009
Temp (F)
RH (%)
90
85
80
75
70
65
60
55
50
45
40
35
30
10/31/2009 12:00:00 PM
11/5/2009 12:00:00 PM
11/10/2009 12:00:00 PM
11/15/2009 12:00:00 PM
11/20/2009 12:00:00 PM
Date/Time

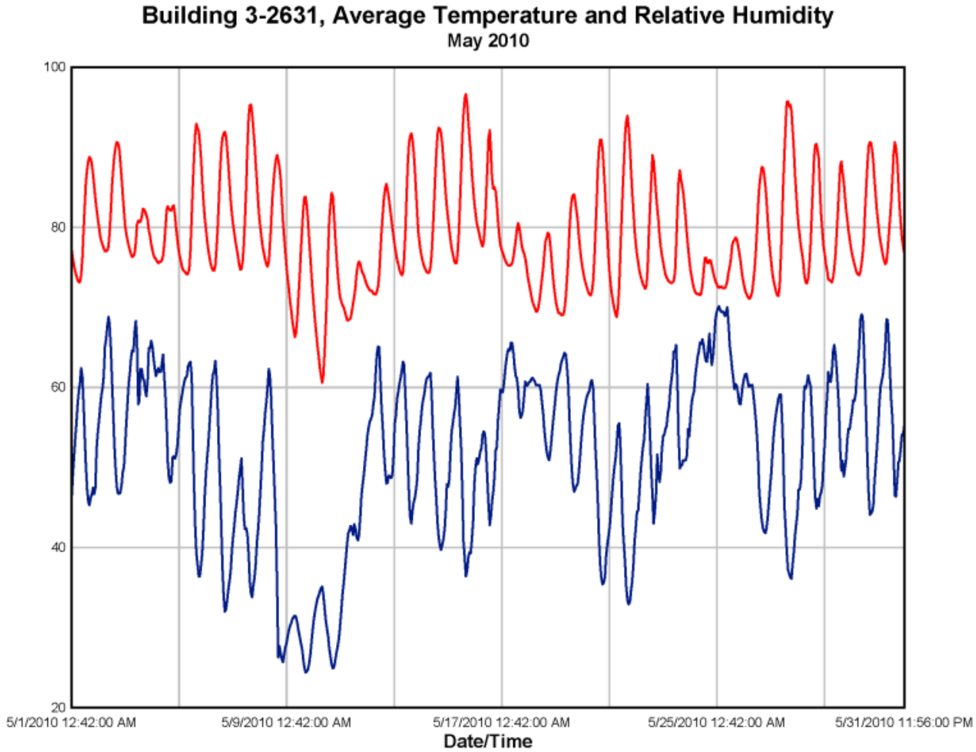

Building 3-2631, Average Temperature and Relative Humidity
December 2009
75
70
65
60
55
50
45
40
35
30
25
20
12/2/2009 12:00:00 AM
12/8/2009 12:00:00 AM
12/14/2009 12:00:00 AM
12/20/2009 12:00:00 AM
12/26/2009 12:00:00 AM
1/1/2010 12:00:00 AM
Date/Time

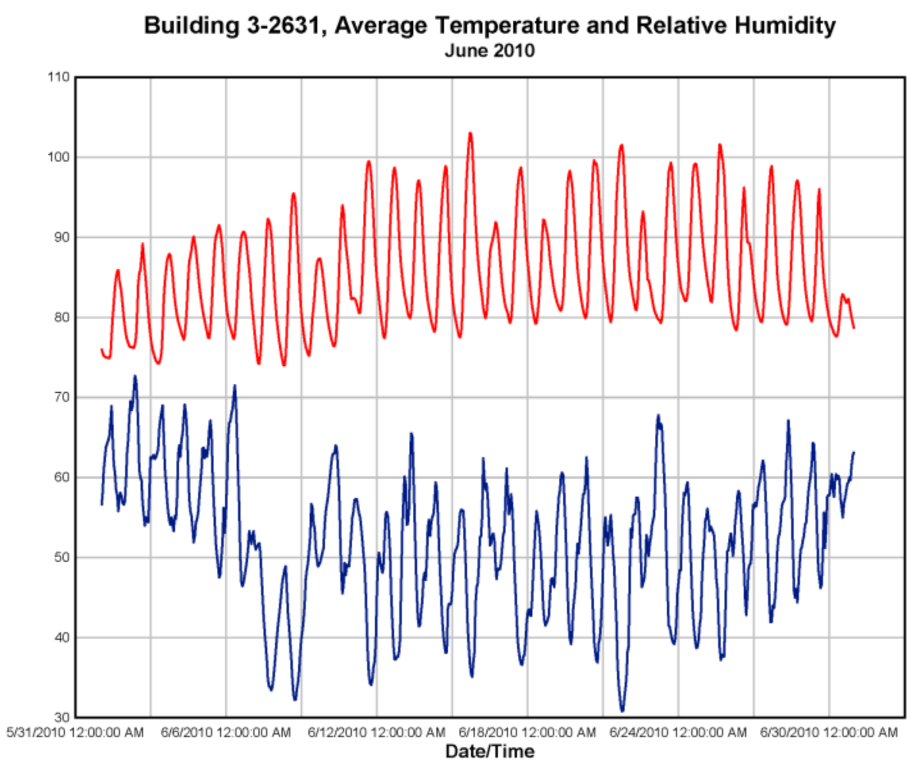

Building 3-2631, Average Temperature and Relative Humidity
January 2010
80
70
60
50
40
30
20
1/1/2010 12:04:00 AM
1/9/2010 12:04:00 AM
1/17/2010 12:04:00 AM
1/25/2010 12:04:00 AM
1/31/2010 11:56:00 PM
Date/Time

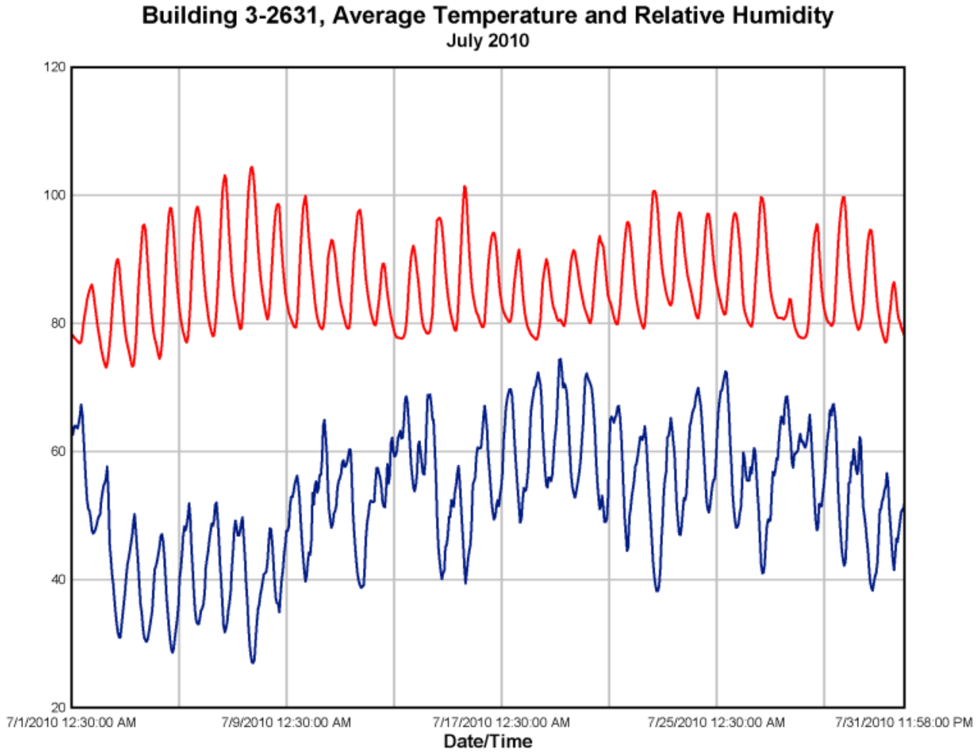

Building 3-2631, Average Temperature and Relative Humidity
February 2010
80
75
70
65
60
55
50
45
40
35
30
25
20
1/31/2010 12:00:00 AM
2/6/2010 12:00:00 AM
2/12/2010 12:00:00 AM
2/18/2010 12:00:00 AM
2/24/2010 12:00:00 AM
3/2/2010 12:00:00 AM
Date/Time

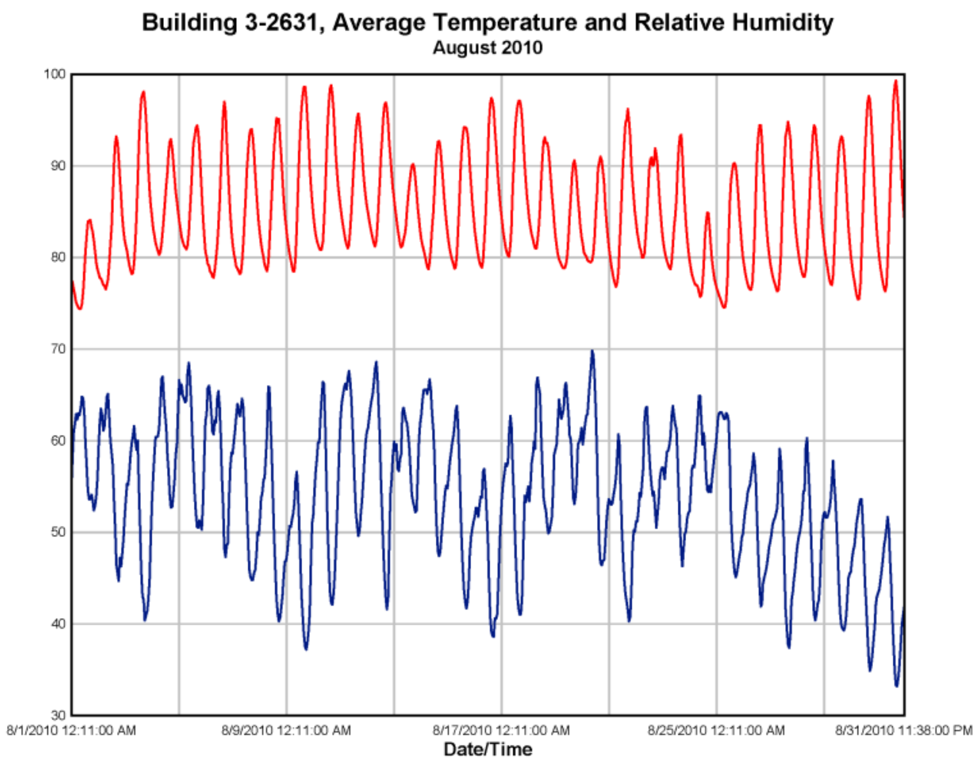

Building 3-2631, Average Temperature and Relative Humidity
March 2010
100
80
60
40
20
0
3/1/2010 12:34:00 AM
3/9/2010 12:34:00 AM
3/17/2010 12:34:00 AM
3/25/2010 12:34:00 AM
3/31/2010 11:19:00 PM
Date/Time

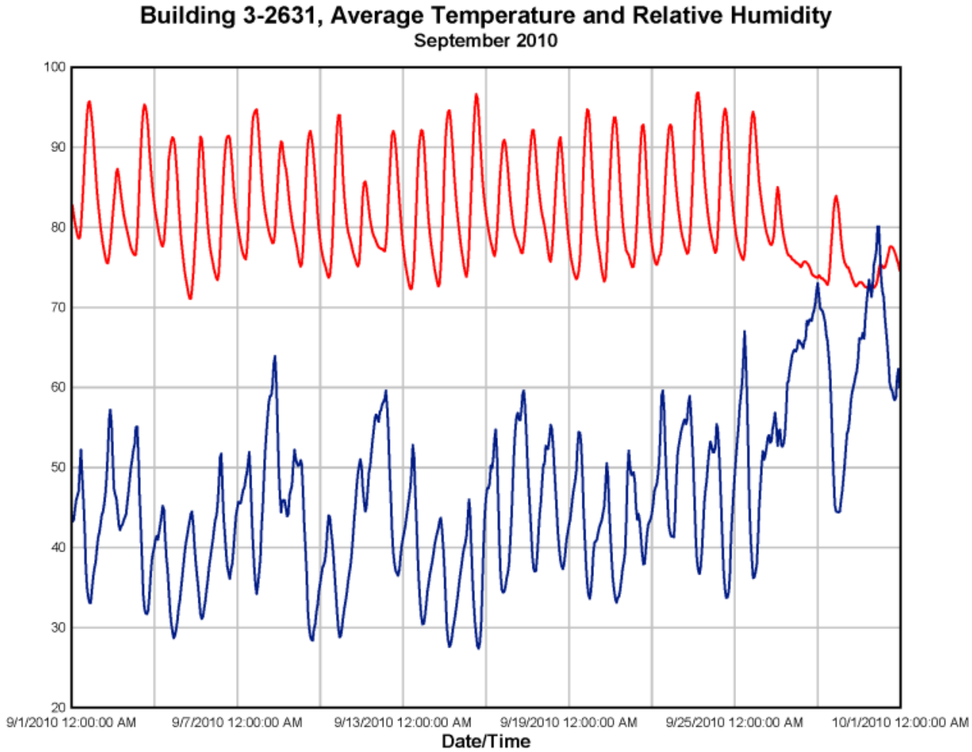

Building 3-2631, Average Temperature and Relative Humidity
April 2010
100
90
80
70
60
50
40
30
20
4/1/2010 12:00:00 AM
4/7/2010 12:00:00 AM
4/13/2010 12:00:00 AM
4/19/2010 12:00:00 AM
4/25/2010 12:00:00 AM
5/1/2010 12:00:00 AM
Date/Time

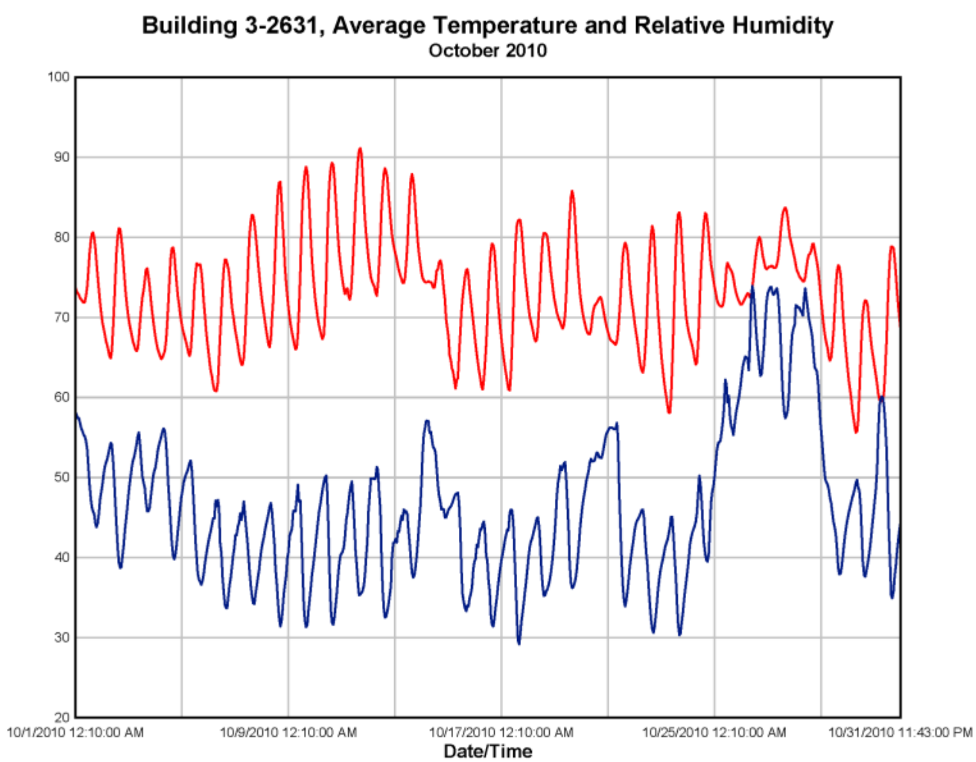

Building 3-2631, Average Temperature and Relative Humidity
May 2010
100
80
60
40
20
5/1/2010 12:42:00 AM
5/9/2010 12:42:00 AM
5/17/2010 12:42:00 AM
5/25/2010 12:42:00 AM
5/31/2010 11:56:00 PM
Date/Time

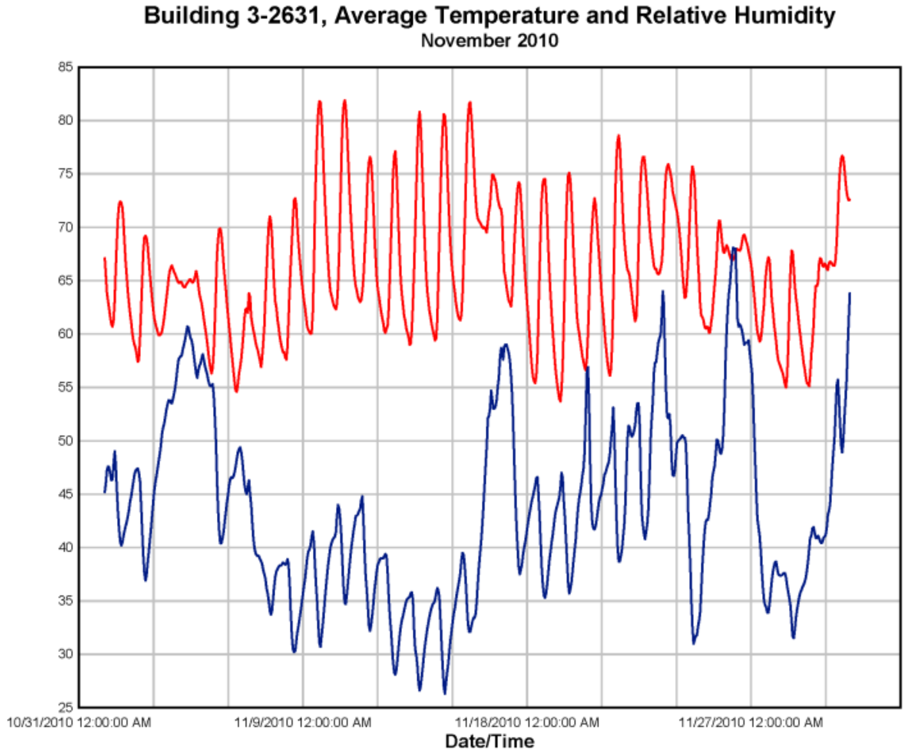

Building 3-2631, Average Temperature and Relative Humidity
June 2010
110
100
90
80
70
60
50
40
30
5/31/2010 12:00:00 AM
6/6/2010 12:00:00 AM
6/12/2010 12:00:00 AM
6/18/2010 12:00:00 AM
6/24/2010 12:00:00 AM
6/30/2010 12:00:00 AM
Date/Time

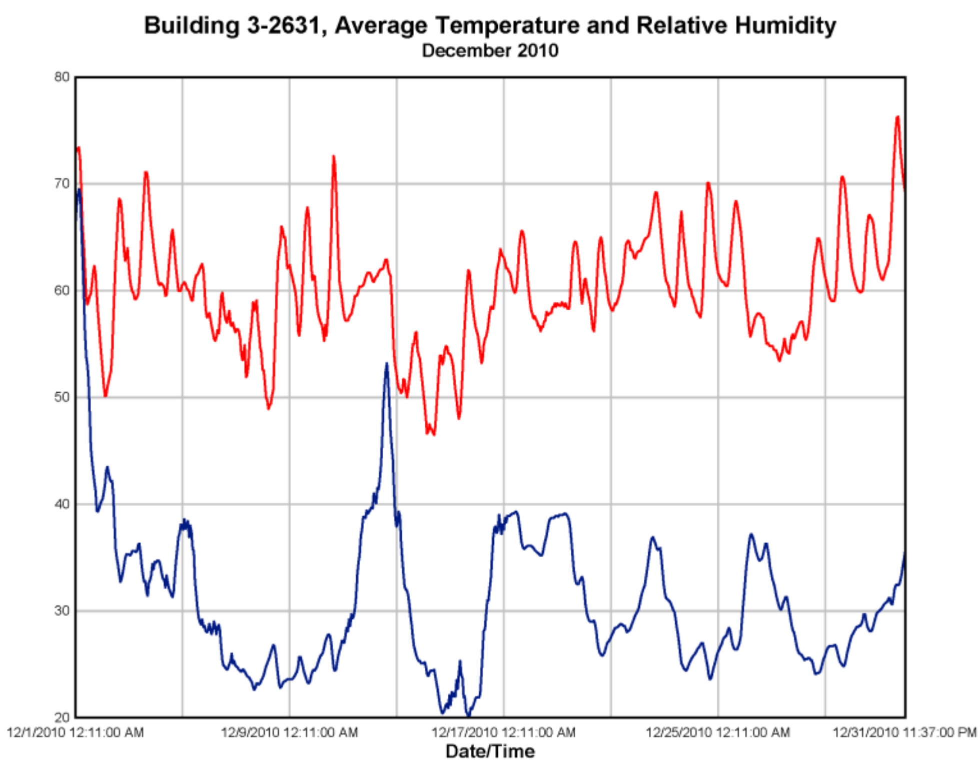

Building 3-2631, Average Temperature and Relative Humidity
July 2010
120
100
80
60
40
20
7/1/2010 12:30:00 AM
7/9/2010 12:30:00 AM
7/17/2010 12:30:00 AM
7/25/2010 12:30:00 AM
7/31/2010 11:58:00 PM
Date/Time

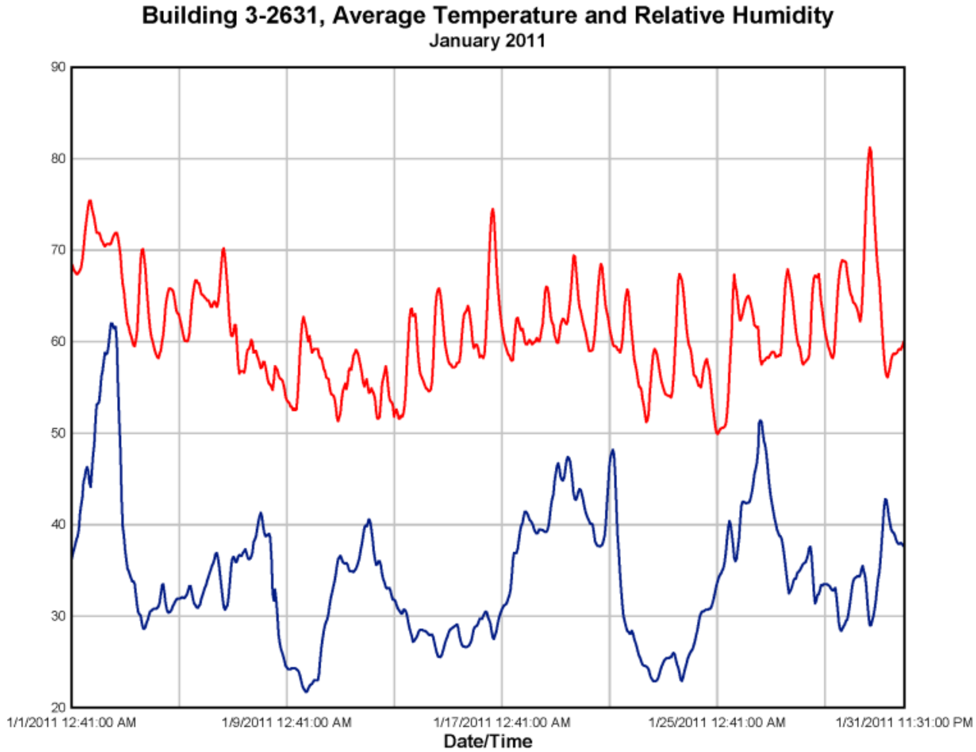

Building 3-2631, Average Temperature and Relative Humidity
August 2010
100
90
80
70
60
50
40
30
8/1/2010 12:11:00 AM
8/9/2010 12:11:00 AM
8/17/2010 12:11:00 AM
8/25/2010 12:11:00 AM
8/31/2010 11:38:00 PM
Date/Time

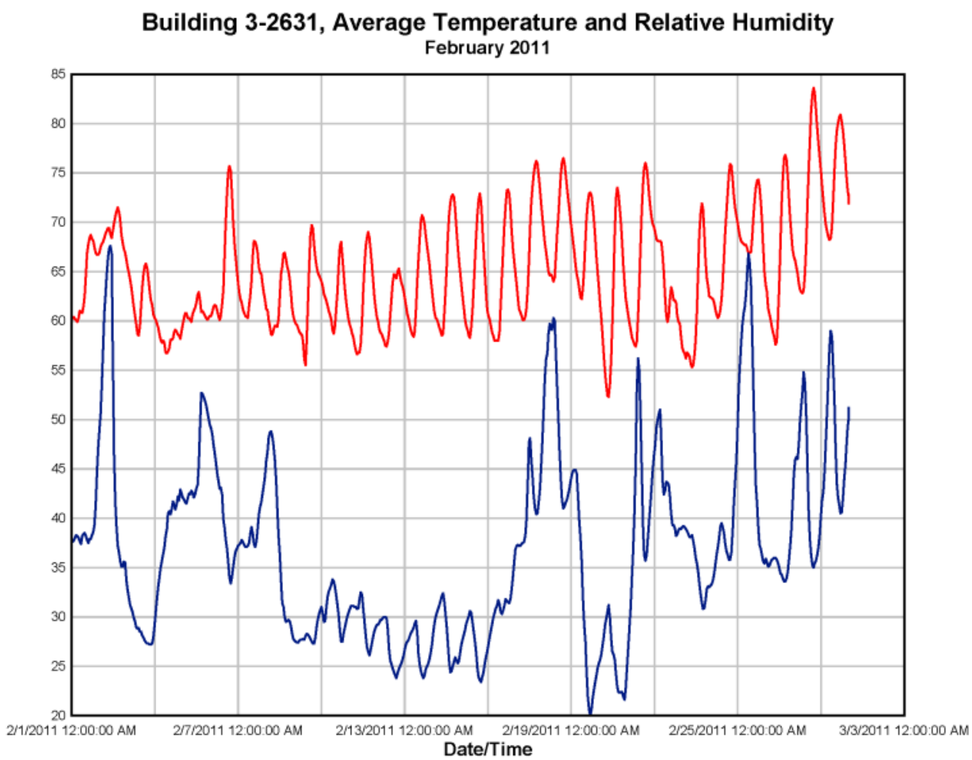

Building 3-2631, Average Temperature and Relative Humidity
September 2010
100
90
80
70
60
50
40
30
20
9/1/2010 12:00:00 AM
9/7/2010 12:00:00 AM
9/13/2010 12:00:00 AM
9/19/2010 12:00:00 AM
9/25/2010 12:00:00 AM
10/1/2010 12:00:00 AM
Date/Time


Building 3-2631, Average Temperature and Relative Humidity
October 2010
100
90
80
70
60
50
40
30
20
10/1/2010 12:10:00 AM
10/9/2010 12:10:00 AM
10/17/2010 12:10:00 AM
10/25/2010 12:10:00 AM
10/31/2010 11:43:00 PM
Date/Time


Building 3-2631, Average Temperature and Relative Humidity
November 2010
85
80
75
70
65
60
55
50
45
40
35
30
25
10/31/2010 12:00:00 AM
11/9/2010 12:00:00 AM
11/18/2010 12:00:00 AM
11/27/2010 12:00:00 AM
Date/Time


Building 3-2631, Average Temperature and Relative Humidity
December 2010
80
70
60
50
40
30
20
12/1/2010 12:11:00 AM
12/9/2010 12:11:00 AM
12/17/2010 12:11:00 AM
12/25/2010 12:11:00 AM
12/31/2010 11:37:00 PM
Date/Time


Building 3-2631, Average Temperature and Relative Humidity
January 2011
90
80
70
60
50
40
30
20
1/1/2011 12:41:00 AM
1/9/2011 12:41:00 AM
1/17/2011 12:41:00 AM
1/25/2011 12:41:00 AM
1/31/2011 11:31:00 PM
Date/Time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February 2011
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13. SUPPLEMENTARY NOTES

14. ABSTRACT

The purpose of this Corrosion Prevention and Control (CPC) demonstration was to investigate the life-cycle cost impact of three corrosion-resistant roofing technologies that provide several secondary benefits over the outdated roofing systems they replace. Fort Bragg, NC, was selected as the location to demonstrate (1) a heat-resistant metal shingle roofing system with above-sheathing ventilation (ASV), (2) a sloped-roof conversion using standing-seam metal roofing system with heat-shedding coating, and (3) a fiberglass-reinforced plastic (FRP) panel roofing system with ultraviolet (UV) radiation protection. Metrics were established to evaluate improvements in performance, corrosion resistance, and energy efficiency over older conventional roofing. Performance was documented through data collection, observation, and reports by facility users.

None of the demonstrated technologies was found to provide sufficient return on investment (ROI) to warrant their selection solely to improve building energy efficiency. The ASV and slope-conversion methods could be modified to reduce first costs to improve their applicability in properly selected cases. The FRP panel roofing provides a modest ROI and provides interior daylighting benefits in applications such as equipment maintenance sheds and workshops without climate control.

15. SUBJECT TERMS

corrosion, roofs, energy efficiency, architectural daylighting, fiberglass-reinforced plastic (FRP), standing-seam metal roofs (SSMR)

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